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Pretreatment of Hazardous Waste

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PRETREATMENT OF HAZARDOUS WASTE

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. the Hazardous Waste Engineering Resarch Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments and the need of both large and small business in handling their wastes responsibily and economically.

This report describes the waste applicability and performance characteristics of hazardous waste pretreatment processes. Pretreatment processes are those unit operations that must often be carried out on hazardous wastes to make them amenable to subsequent materials or energy recovery steps, to chemical or biological detoxification, thermal destruction, or safe land disposal. The pretreatment processes covered are primarily phase separation (flotation, filtration, distillation, etc.) and component separation (adsorption, stripping, solvent extraction, etc.) techniques. Methods for selecting the appropriate pretreatment process are provided as a function of waste characteristics, treatment objective, technical adequacy, performance, and cost and energy considerations. Detailed summaries are provided for the various techniques along with relevant performance data.

For further information, please contact the Alternative Technologies Division of the Hazardous Waste Engineering Research Laboratory.

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This report describes the waste applicability and performance characteristics of hazardous waste pretreatment processes. Pretreatment processes are those unit operations which must often be carried out on hazardous wastes to make them amenable to subsequent materials or energy recovery steps, to chemical or biological detoxification, thermal destruction or safe land disposal. The pretreatment processes covered are primarily phase separation (floatation, filtration, distillation, etc.) and component separation (adsorption, stripping, solvent extraction, etc.) techniques. Methods for selecting the appropriate pretreatment process are provided as a function of waste characteristics, treatment objective, technical adequacy, performance, and cost and energy considerations. Detailed summaries are provided for the various techniques along with relevant performance data.

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PRETREATMENT OF HAZARDOUS WASTE

I. Introduction

Indiscriminate dumping of industrial processing wastes can lead to groundwater contamination, or have other adverse effects, often 40 or 50 years after the initial waste disposal. Although methods have been explored to reduce leaching into the groundwater, by, for example, encapsulating wastes prior to burial, and/or placement in secure landfills it is far more certain to control contaminants by waste minimization, reuse, treatment, or destruction.

Currently, the United States has few restrictions on wastes that are land disposed. However, the Hazardous and Solid Waste Act Amendments of 1984 have set in motion many new programs that increase the level of control of hazardous wastes and, in particular, the land disposal of hazardous wastes. The Amendments require the U.S. Environmental Protection Agency (EPA) to develop regulations banning all hazardous waste from land disposal unless it is determined that land disposal of specific wastes will be protective of public health and the environment as long as the waste remains hazardous. While it is likely that certain wastes will continue to be land disposed, the course has been clearly set to direct wastes to the preferred alternative methods of minimization, treatment, reuse, or destruction.

II. Waste Treatment

Because of the many valid reasons for reducing the amount and number of classifed hazardous wastes that can be deposited in controlled land sites, it is important that treatment processes be identified and applied as a part of an overall hazardous waste management system. The objective of this report is to describe the waste applicability and performance characteristics of hazardous

waste pretreatment processes. Pretreatment processes are those unit operations which must often be carried out on hazardous wastes to make them amenable to subsequent materials or energy recovery, to chemical or biological detoxification, thermal destruction or safe land disposal. As such, pretreatment really describes the manner in which a treatment process is applied in an overall waste management system rather than a specific set of unit processes. Table 1 lists unit operations currently believed to be useful in hazardous waste treatment. In most instances, a number of these processes would be combined to form a complete treatment system for a particular waste stream. The number and type of processes employed are a function of the degree of ultimate treatment required (e.g., component removal prior to land disposal versus complete detoxification).

Physical treatment processes are most often used as pretreatment steps. Chemical steps such as neutralization, oxidation, or precipitation are also used to pretreat wastes. These processes are covered in more detail in a companion document on chemical and biological treatments prepared for this Seminar and will not be discussed in detail in this report. Detailed descriptions of physical treatment processes are provided in Section V of this report along with treatment performance data.

III. Pretreatment Processes

Physical pretreatment processes typically are designed to perform one of two functions; phase separation or component separation.

A. Phase Separation

Waste streams, such as slurries, sludges and emulsions, will often require a phase-separation process (Table 2) before detoxification or recovery steps can be implemented. Frequently, phase separation permits a significant volume

TABLE 1

HAZARDOUS WASTE TREATMENT PROCESSES

Physical	Chemical
Air Stripping	Chemical Stabilization
Carbon Adsorption	Catalysis
Centrifugation	Chlorinolysis
Distillation	Electrolysis
Electrodialysis	Hydrolysis
Evaporation	Microwave Discharge
Filtration	Neutralization
Flocculation	Oxidation
Flotation	Ozonolysis
Freeze Crystallization	Photolysis
Ion Exchange	Precipitation
Liquid Ion Exchange	Reduction
Steam Distillation	
Resin Adsorption	Biological
Reverse Osmosis	
Sedimentation	Activated Sludge
Liquid-Liquid Extracting of Organics	Aerated Lagoon
Steam Stripping	Anaerobic Digestion
Ultrafiltration	Composting
	Enzyme Treatment
	Trickling Filter
	Waste Stabilization Pond

TABLE 2

PHASE SEPARATION PROCESSES APPLICABLE IN HAZARDOUS WASTE PRETREATMENT

	PROCESS APPLICABILITY			
Process Category	Settleable Slurries	Colloidal Slurries	Sludges	Waste With A Volatile Liquid Phase
Common Use	Sedimentation Filtration	Flocculation	Filtration	Solar Evaporation Distillation
Developed But Less Commonly Used	Centrifugation			Evaporation
Development Stage	Flotation	Ultrafiltration	Freezing	

reduction, particularly if the hazardous component is present to a significant extent in only one of the phases. Furthermore, by concentrating the hazardous portion of the stream, sequential processing steps may be accomplished more readily. Phase-separation processes usually are mechanical, inexpensive and simple, and can be applied to a broad spectrum of wastes and waste components.

Emulsions are generally very difficult to separate. Heating, cooling, change of pH, salting out, centrifugation, API separators, etc., may all be tried, but there is no accurate way to predict what might work. Appropriate methods can only be developed empirically, specific to any given situation.

1. Settlable Slurries

Conceptually, the simplest separation process is sedimentation, or gravity settling. The output streams will consist of a sludge and a decantable supernatant liquid. If the components of the sludge are at all soluble, the supernatant liquid generally will be a solution. A closely related process and the phase separation process in most common use is filtration. Centrifugation is essentially a high gravity sedimentation process whereby centrifugal forces are used to increase the rate of particle settling. Flotation is used extensively in ore separation, and in fact is the single most important process that has made it possible to recover value from lower and lower grades of metallic and non-metallic ores. Flotation is also applicable to separation of oily or light fractions of aqueous waste streams.

2. Colloidal Slurries

The basic concept in all the above processes for settlable slurries is to get the solid phases to drop out of the liquid phase, through the use of gravitational, centrifugal, magnetic, or hydrostatic forces. Such forces generally do not act on colloidal suspended particles.

The simplest and most commonly used colloidal separation process is flocculation. Ultrafiltration has many industrial applications, including waste treatment, and is expected to have many more within the next five years.

3. Sludges

The major phase separation desired in the handling of sludges is dewatering. Vacuum filtration or press filtration are the processes in most common use. Some research has been done on simple freezing, but the process is not well developed and the work that has been done is not promising.

4. Volatiles

Sludges and slurries (colloidal or separable) in which the liquid phase is volatile may be treated by either evaporation or distillation. Solar evaporation is very commonly used although this approach is likely to be limited in the future by pending control standards for hazardous organic compound emissions to the atmosphere. Engineered evaporation or distillation systems would normally be operated if recovery of the liquid is desired.

B. Component Separation

Many physical processes act to segregate ionic or molecular species from multicomponent waste streams but do not require chemical reactions to be effective. There has been a great deal of experience developed from application of these processes in industrial and municipal wastewater treatment. Since a significant number of hazardous wastes generated in the United States are aqueous streams, these processes are seeing increasing use in this emerging field of waste treatment.

The applicability of component separation processes to various classes of treatment functions is shown in Table 3. Complete descriptions of each unit

process are given in Section V. In many cases component separation may be the only treatment required to make a waste suitable for land disposal or discharge to municipal wastewater treatment systems.

IV. Selection Of Pretreatment Processes For Given Waste Streams

A. Philosophy Of Approach

There are a variety of ways to approach the problem of selecting the appropriate process(es) for pretreatment of a particular waste stream. Individual engineers, chemists, equipment manufacturers, salesmen, environmental managers, plant managers, regulatory authorities, etc., will each have slightly different perspectives on the problem, different data needs, and different ways of manipulating the data to reach a final conclusion. No one approach is necessarily "right" for everyone or best for any given situation. No matter how one approaches the problem of process selection, there are two seemingly conflicting criteria to keep in mind. The first is to eliminate inappropriate processes from consideration at the earliest stage feasible. The second is to maintain an open mind for consideration of attractive processes as long as possible.

B. Pretreatment Process Selection

The selection of hazardous waste pretreatment systems is governed by four factors. These are:

- nature of the waste stream
- treatment objective
- technical adequacy of pretreatment alternative
- economic and energy considerations

The importance of these factors is discussed below. Also matrices are presented which may serve as a general guide for using these factors in pretreatment process selection.

TABLE 3

COMPONENT SEPARATION PROCESSES

Process Category	Function Of Process: Removal Of Heavy Metal And Toxic Anions From Aqueous Solutions	Removal Of Organics From Aqueous Solutions	Removal Of In-Organics From Liquids, Slurries And Sludges	Solvent Recovery
Common Use	Ion Exchange	Carbon Adsorption		Distillation
		Steam Stripping		Steam Distillation
Developed, But Less Commonly Used	Liquid Ion Exchange	Ultrafiltration		Evaporation
	Electrodialysis	Solvent Extraction		
	Reverse Osmosis	Resin Adsorption		
		Air Stripping		
Development Stage			Solvent Extraction	
			Freeze Crystallization	

1. Nature of the Waste Stream

For the purposes of identifying possible pretreatment processes, and eliminating those that are not likely to prove useful, a given waste stream is conveniently characterized with respect to three broad dimensions:

- physical form - e.g., liquid, emulsion, slurry, solid, powder
- hazardous components - e.g., heavy metal cations, organics
- other properties - e.g., components by waste phase, aqueous versus non-aqueous, concentration of pollutant

It is important to assess the nature of the waste stream for several reasons. One is to determine whether the waste stream characteristics match the feed stream requirements for various pretreatment processes. In a positive sense, this may be of interest to select processes for further consideration; or in a negative sense, to rule out processes that are not and could not be made useful for the particular waste under any circumstances. Another is to determine whether the waste stream is compatible with typical treatment process equipment, materials of construction, pumps, throughput rates, temperature, size of pipes, etc. A third reason is to determine whether air and water pollution controls, or the method of waste collection used, might in fact create a stream which is more difficult to treat than the waste originally generated in the manufacturing operation.

For a given waste stream, characterized by physical form and hazardous components, the matrix presented in Table 4 may be used to select potentially applicable pretreatment processes. For example, liquid ion exchange (LIE) might be capable of removing heavy metals from solid powders. The matrix in Table 5 focusses on processes that are inapplicable for given waste streams. It provides

TABLE 4

PRETREATMENT PROCESSES FOR HAZARDOUS COMPONENTS IN WASTE STREAMS OF VARIOUS PHYSICAL FORMS

Physical Form	Treatment Processes		
	Heavy "Metal" Cations* And Metal Anions**	Non-Metal Anions***	Organics
Liquid	(IE), (FC), (UF), (ED), (RO), (LIE), (Ppt)	(CA), (LIE), (FC), (UF), (ED), (RO)	(CA), (RA), (Dis), (IE), (AS), (SS), (UF), (SE), (RO), (UF)
Emulsion	(UF)		
Slurry	(FC), (UF)	(FC), (UF)	(Dis), (AS), (SS), (UF),
Sludge	(LIE), (FC)	(FC)	(Dis)
Solid Powder	(LIE)		

Legend:

(AS) Air Stripping
(CA) Carbon Adsorption
(Dis) Distillation
(ED) Electrodialysis
(FC) Freeze Crystallization
(IE) Ion Exchange
(LIE) Liquid Ion Exchange
(Ppt) Precipitation
(RA) Resin Adsorption
(RO) Reverse Osmosis
(SE) Solvent Extraction
(SS) Steam Stripping
(UF) Ultrafiltration

*e.g., Sb, As, Cd, Cr, Hg, PB, Zn, Ni, Co, V, P, Be, Se, Mn, Ti, Sn, Ba
**e.g., chromates, arsenates, arsenites, vanadates
***e.g., cyanides, sulfides, fluorides, hypochlorites, thiocyanates

TABLE 5

APPLICABILITY OF TREATMENT PROCESSES TO PHYSICAL FORM OF WASTE

	Single Phase				Two Phases	
		Liquid				
	Solid	Inorganic	Organic	Mixed	Slurry*	Sludge
1. Phase Separation Processes						
Filtration	n	n	n	n	y	n
Sedimentation	n	n	n	n	y	n
Flocculation	n	n	n	n	n	n
Centrifugation	n	n	n	n	y	n
Distillation	n	n	n	n	y	y
Evaporation	n	n	n	n	y	y
Flotation	n	n	n	n	y	n
Ultrafiltration	n	n	n	n	n	n
Precipitation	n	n	n	n	n	n
2. Component Separation Processes						
Ion Exchange	n	y	y	y	n	n
Liquid Ion Exchange	y	y	y	y n	y	y
Freeze Crystallization	n	y	y	n	y	y
Reverse Osmosis	n	y	n			
Carbon Adsorption	n	y				
Resin Adsorption	n	y				
Electrodialysis	n	y				
Air Stripping	n	n	y	y	y	n
Steam Stripping	y	n	y	y	y	n
Ammonia Stripping	y	y	n	n	n	n
Ultrafiltration	n	y	y	y	n	n
Solvent Extraction	p	y	y	y	n	n
Reverse Osmosis	n	y	n	y	n	n
Distillation	n	n	y	y	y	y
Evaporation	n	y	y	y	y	y

*Slurry is defined here as a pumpable mixture of solids and liquids
y = yes, workable; n = no; p = possible.

some guidance for ruling out processes that are not likely to be technically feasible for certain types of waste streams.

2. Treatment Objective

The output streams from any given pretreatment process may or may not be suitable for input to subsequent reuse or treatment steps. In evaluating and analyzing pretreatment processes that might be applicable to particular waste streams, it is usually necessary at some stage to define the objectives of pretreatment and the desired characteristics of the output streams from each step in the overall process train.

For example, if the treatment objective is to convert the given waste stream to one or more streams which can legally be discharged to a water body, the Federal and local waste pollution control regulations will govern the characteristics of the output streams. If the treatment objective is recovery, those processes must be sought which either lead directly to a reusable resource, or which convert the waste to a form from which resources may be more easily recovered.

Table 6 provides some general characteristics of the output streams (end products) from various processes to aid in assessing their capability, alone or in combination, to meet defined objectives. Where processes are routinely or conveniently used in combination, follow-on steps are suggested, predicated on the assumption that the only hazardous components in the waste stream are those that the process listed can act on. If, for example, a waste stream containing both low-molecular-weight organic and heavy metal contaminants was treated by reverse osmosis, only the heavy metals would be concentrated in one of the output streams (RO1), and the other output stream (RO2) would have to be treated further to remove or detoxify the organics.

TABLE 6 (Continued)

GENERAL CHARACTERISTICS OF THE END-PRODUCTS OF TREATMENT PROCESSES

Treatment		Output Streams		Possible Follow-On Steps
Type	Process	Form	Characteristics	
	Electrodialysis	Liquid	concentrated stream, 100-500 ppm salts	Precipitation, Metal Recovery
		Liquid	dilute stream	To Water Treatment
	Freeze Crystallization	Sludge	concentrated brine	Recovery
		Liquid	purified stream, ~100 TDS	To Water Treatment
b. Organics	Carbon Adsorption	Solid	adsorbate on carbon	Thermal or Chemical Regeneration
		Liquid	purified water	Discharge
	Resin Adsorption	Solid	adsorbate on resin	Solvent Regeneration
		Liquid	purified water, <10 ppm organics	To Water Treatment
	Steam Stripping	Liquid	aqueous stream concentrated in volatile organics	Recovery; Incineration
		Liquid	dilute aqueous stream with 50-100 ppm organics	
	Solvent Extraction	Liquid	concentrated solution of hazardous components in extraction solvent	Recovery of Extraction Solvent
		Liquid	purified liquid; hazardous component concentration <10 ppm	Recycle of Discharge
	Distillation	Sludge	still bottoms	Incineration
		Liquid	pure liquid	Sale

TABLE 6 (Continued)

GENERAL CHARACTERISTICS OF THE END-PRODUCTS OF TREATMENT PROCESSES

1. Phase Separation	Filtration	Sludge Liquid	15-20% solids 500-5000 ppm total dissolved solids	Landfill, Calcination Component Separation
	Sedimentation	Sludge	2-15% solids	Decantation
	Centrifugation	Liquid	10-200 ppm suspended solids	Landfill
	Flotation	Stabilized Liquid	particle-bearing froth solution	Skimming Component Separation
	HGMS	Slurry Liquid	magnetic and paramagnetic particles solution	Recovery Component Separation
	Flocculation	Sludge or Slurry	flocculated particulates	Sedimentation, Filtration, Centrifugation
	Distillation	Sludge Liquid	still bottoms pure solvent	Calcination Sale
	Evaporation	Solid Liquid	- condensate	Resource Recovery Recovery or Disposal
2. Component Separation				
a. Inorganics	Ion Exchange	Liquid Liquid	concentrated solution of hazardous components purified water with hazardous components at ppm levels	Precipitation, Recycle, Electrolysis Discharge
	Liquid Ion Exchange	Similar To Ion Exchange		
	Carbon Adsorption	Solid Liquid	adsorbate on carbon purified water	Chemical Regeneration Discharge
	Reverse Osmosis	Liquid Liquid	concentrated solution of hazardous components purified solution, TDS >5 ppm	Precipitation, Electrolysis, Recycle

3. Technical Adequacy of Pretreatment Alternatives

Table 4 shows that there are a number of pretreatment alternatives for various types of hazardous components in waste streams of different physical form. All processes which function similarly on similar types of waste streams are not necessarily technically equivalent, however. The available feed stream concentrations may differ. The pretreatment efficiencies and hence concentration of hazardous components in the output streams may differ. The degree of interference by other components in the waste stream may differ. Throughputs may differ and the available experience with using the processes to treat hazardous wastes may also differ.

Table 7 compares treatment processes capable of separating heavy metals from liquid waste streams with respect to feed stream properties and output parameters. Tables 8 and 9 provide similar comparisons for processes that separate organics and toxic anions from liquids. Table 10 compares processes that can accept feed streams in the form of slurries and sludges.

4. Economic and Energy Considerations

From the industry point of view, economic questions are paramount in selecting alternative pretreatment methods for in-plant use and in choosing a waste treatment facility. Some of the important questions which must be considered when evaluating economic factors are:

- What are the energy requirements for process operation?
- What form(s) of energy will be used, i.e., electricity, natural gas, oil, coal, etc.

TABLE 7

COMPARISON OF PROCESSES THAT SEPARATE HEAVY METALS FROM LIQUID WASTE STREAMS

Process	Required Feed Stream Properties	Characteristics of Output Streams(s)
Physical Removal		
Ion Exchange	Con. <4000 ppm; aqueous solutions, low SS	One concentrated in heavy metals; one purified
Reverse Osmosis	Con. <400 ppm; aqueous solutions; controlled pH; low SS; no strong oxidants	One concentrated in heavy metals; one with heavy metal concentrations >5 ppm
Electrodialysis	Aqueous solutions; neutral or slightly acidic; Fe and Mn <0.3 ppm; Cu <400 ppm	One with 1000-5000 ppm heavy metals; one with 100-500 ppm heavy metals
Freeze Crystallization	Aqueous solutions; TDS <10%	Concentrated brine or sludge; purified water, TDS ~100 ppm

TABLE 8

COMPARISON OF TREATMENT PROCESSES THAT SEPARATE ORGANICS FROM LIQUID WASTE STREAMS

Treatment Processes	Required Feed Stream Properties	Characteristics Of Output Stream(s)
Carbon Adsorption	Aqueous solutions; concentrations <1%; SS <50 ppm	Adsorbate on carbon; usually regenerated thermally or chemically
Resin Adsorption	Aqueous solutions; concentrations <8%; SS <50 ppm; no oxidants	Adsorbate on resin; always chemically regenerated
Ultrafiltration	Solution or colloidal suspension or high molecular weight organics	One concentrated in high molecular weight organics; one containing dissolved ions
Air Stripping	Solution containing ammonia; high pH	Ammonia vapor in air
Steam Stripping	Aqueous solutions of volatile organics	Concentrated aqueous streams with volatile organics and dilute steam with residuals
Solvent Extraction	Aqueous or non-aqueous solutions; concentration <10%	Concentrated solution of organics in extraction solvent
Distillation	Aqueous or non-aqueous solutions; high organic concentrations	Recovered solvent; still bottoms liquids, sludges and tars
Steam Distillation	Volatile organics, non-reactive with water or steam	Recovered volatiles plus condensed steam with traces of volatiles

TABLE 9

COMPARISON OF PROCESSES THAT SEPARATE TOXIC ANIONS FROM LIQUID WASTE STREAMS

Process	Required Feed Stream Properties	Characteristics Of Output Stream(s)
Physical Removal		
Ion Exchange	Inorganic or organic anions in aqueous solution	Concentrated aqueous solutions
Liquid Ion Exchange	Inorganic or organic anions in aqueous solution	Concentrated solutions in extraction solvent
Electrodialysis	Aqueous stream with 1000-5000 ppm inorganic salts; and pH; Fe and Mn <0.3 ppm	Concentrated aqueous stream (10,000 ppm salts); dilute stream (100-500 ppm salts)
Reverse Osmosis	Aqueous solutions with up to 34,000 ppm total dissolved solids	Dilute solution (~5 ppm TDS); concentrated solution of hazardous components
Freeze Crystallization	Aqueous salt solutions	Purified water; concentrated brine

TABLE 10

COMPARISON OF PROCESSES THAT CAN ACCEPT SLURRIES OR SLUDGES

Process	Required Feed Stream Properties	Characteristics Of Output Stream(s)
Calcination	Waste stream with components that decompose by volatilization (hydroxides, carbonates, nitrate, sulfites, sulfates)	Solid greatly reduced in volume; volatiles
Freeze Crystallization	Low-viscosity aqueous slurry or sludge	Brine sludge; purified water
Liquid Ion Extraction	Solvent extractable inorganic component	Solution in extraction solvent
Flotation	Flotable particles in slurry	Froth
Hydrolysis	Hydrolyzable component	Hydrolysis products
Anaerobic Digestion	Aqueous slurry; <7% solids; no oils or grease; no aromatics or long chain hydrocarbons	Sludges; methane and CO_2
Composting	Aqueous sludge; <50% solids	Sludges; leachate
Steam Distillation	Sludge or slurry with volatile organics	Volatile, solid residue
Solvent Extraction	Solvent extractable organic	Solution of extracted components; residual sludge

- To what extent will credit for recovered material help offset operating costs?
- How do projected costs for alternative pretreatments compare with each other?
- If recovery as an objective, is there enough value in the potentially recoverable material to be worthwhile?
- Are the technically optimal operating parameters in the proper range for economic operation of apparently attractive processes?
- If process modifications are required, what will they cost?
- For technically and operationally acceptable processes with equal operating costs (including capital amortization), is there any economic reason to prefer the lowest capital cost alternative?
- What is the cost impact of any necessary environmental controls?

Questions of energy utilization are asked in order to assure that pretreatment processes satisfy current national objectives of both environmental protection and energy conservation. Both the absolute quantity of energy required and the form of the energy required are important. Energy-intensive processes generally would be in disfavor, unless there are compensating benefits (e.g., materials recovery). Processes that use fuels in short supply might be particularly unattractive. The economics of pretreatment processes for which energy costs represent a significant fraction of operating costs would, of course, be tied to the price of fuel, which as in the recent past been quite volatile.

V. Waste Pretreatment Process Summaries

The following pages summarize the salient features of phase separation and component separation processes applicable for hazardous waste pretreatment. Process flow diagrams are included as are general descriptions of process performance.

Gravity separation is limited to removal of settleable solids and oils. Non-settleable material or emulsified oil will not be removed; in these cases, pretreatment with chemicals to enhance settleability or break emulsions or an alternate separation process is required. Heavy, oversized materials should be removed by screens to protect clarifier mechanisms and prevent plugging of parallel plates, sludge piping and pumps. Sticky materials may build up and plug parallel plates, requiring frequent cleaning.

Gravity separation can reduce effluent suspended solids to less than 20 to 50 mg/l. If further reduction is required, an additional process such as filtration is needed.

Applicability to the Treatment of Hazardous Waste

The two main applications for gravity separators in the treatment of hazardous wastes are:

1. pretreatment to remove suspended solids and oils prior to other treatment processes

2. separation of solids generated by other treatment processes, e.g., precipitation and activated sludge.

All of the wastes which are proposed for exclusion from landfills can contain suspended solids or immiscible liquids. These range from metal fragments, filings and tramp oils to pieces of wood, plastic and rags which are simply discarded into waste containers. Gravity separation, in combination with screening and filtration as appropriate, is a simple and effective process for removing these materials.

In many cases where presettling of hazardous waste is required, simple batch holding in a tank is adequate since the volume of waste is often small. Waste holding tanks are often designed with conical bottoms and sludge drawoff connections to permit removal of settled material.

This was common practice at hazardous waste treatment facilities visited. At one large facility, surface impoundments were used for gravity settling with the settled material removed periodically by dredging.

Clarifiers with sludge withdrawal mechanisms are appropriate for separation of the solids produced by biological treatment of aqueous organic wastes or precipitation (continuous flow) of heavy metals from aqueous wastes.

At a commercial hazardous waste treatment facility that was visited by M&E, sludge blanket type clarifiers are used to separate flocculated heavy metal hydroxides and sulfides from a

treated aqueous waste. Underflow sludge having 1-½ to 2 percent solids is periodically pumped out to a 200,000 gallon gravity thickening tank. This second sedimentation process, with a 1.5 day holding time, results in a 6-8 percent solids sludge which is further dewatered in a belt filter press.

Environmental Considerations

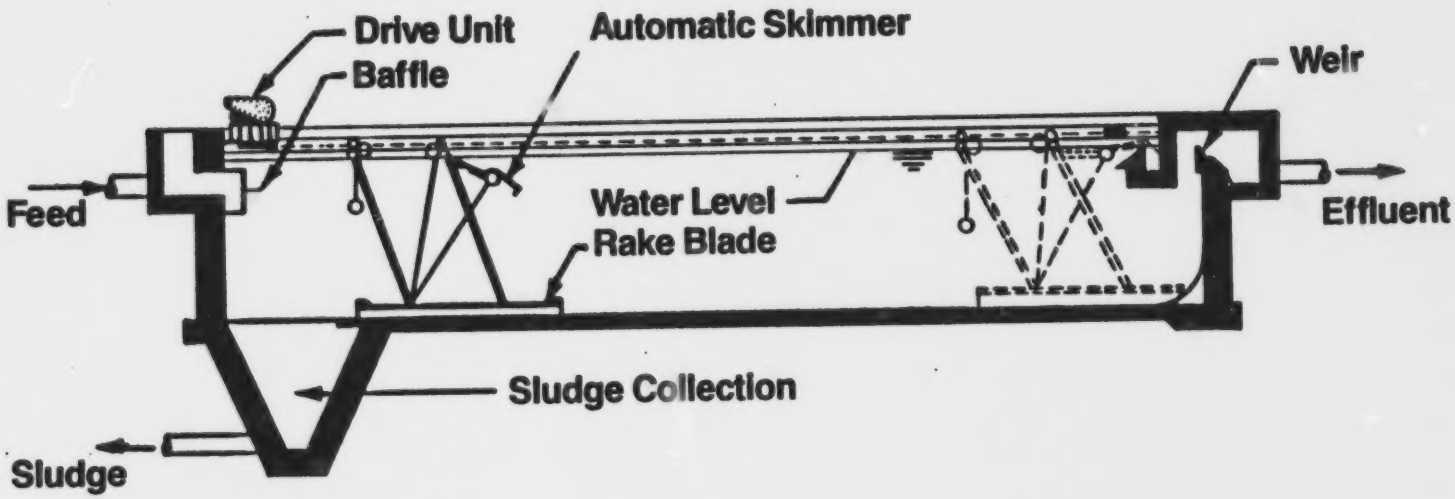
Every sedimentation process procedures:

1. A liquid efffluent which may require further treatment before it can be discharged.

2. Sludge or skimmings which must be further treated, chemically stabilized and/or disposed of.

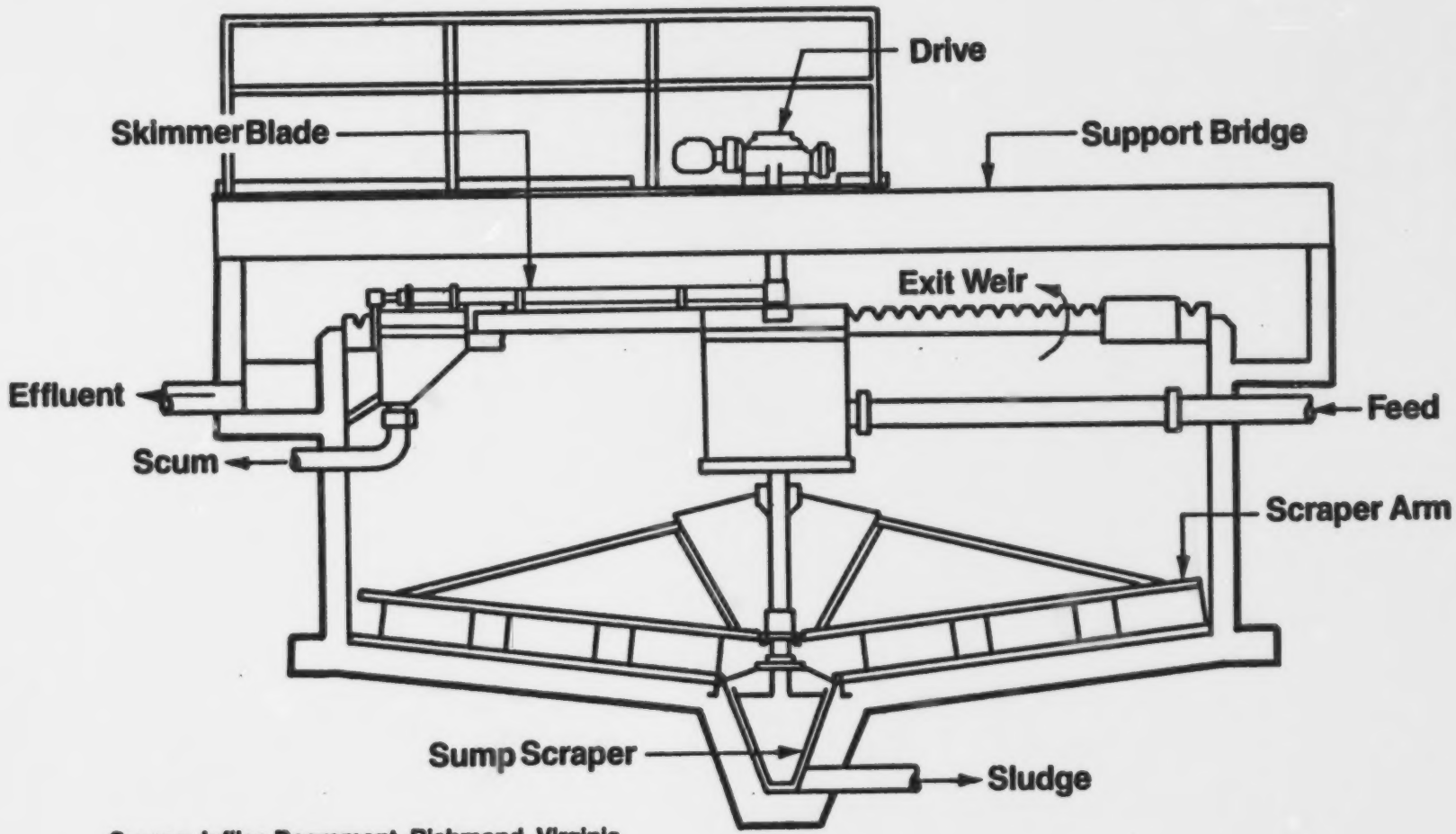
In addition, there is a potential for atmospheric release of volatile chemicals from open-topped clarifiers and sedimentation basins. Often a nominally inorganic aqueous waste will be contaminated wiht hundreds of mg/l of organic solvents. Strong odors above clarifiers used to separate metal precipitates from wastewater have been detected at commercial hazardous waste treatment facilities.

FIGURE 2.1a
RECTANGULAR SEDIMENTATION TANK



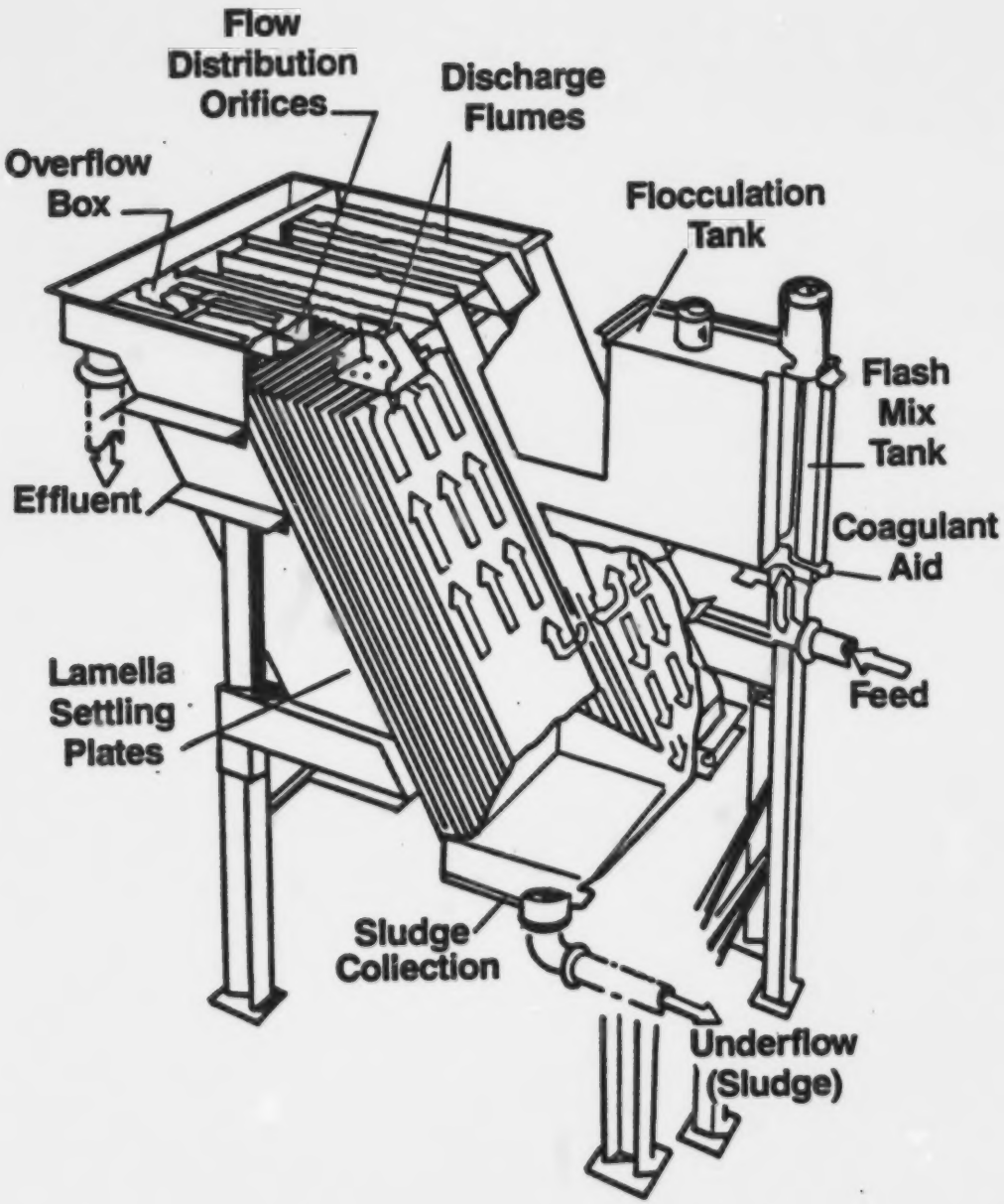
Source: Dorr-Oliver, Stamford, CT

FIGURE 2.1b
CIRCULAR CLARIFIER



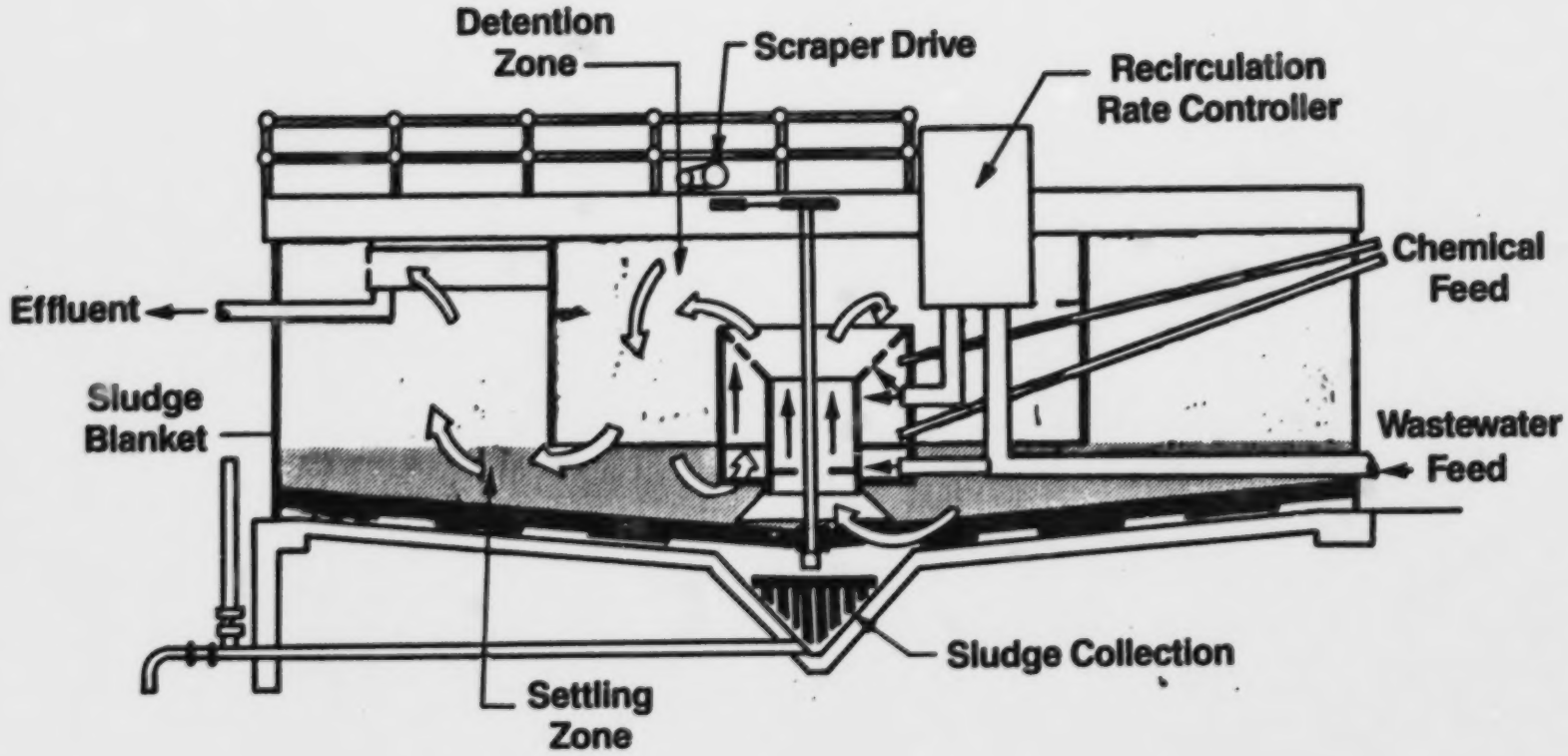
Source: Infilco Degremont, Richmond, Virginia

FIGURE 2.1c
INCLINED PLATES SETTLING UNIT



Source: Parkson Corp., Ft. Lauderdale, Florida

FIGURE 2.1d
SOLIDS CONTACT REACTIVATOR™



Source: Ecodyne Corporation, Graver Water Division

SECTION 2.2

FLOTATION

Process Description

Flotation is a gravity separation process in which the attachment of fine air bubbles to suspended solids or oils decreases the effective density of the material, thereby enhancing gravity separation.

There are two major types of flotation processes:

1. dissolved air flotation (DAF)

2. induced air flotation (IAF)

In Dissolved Air Flotation, a portion of the waste feed stream or an effluent recycle stream is saturated with air at a pressure of 40 to 60 psi, then released to atmospheric pressure in a flotation chamber. The sudden pressure reduction results in release of microscopic (50 to 100 micron) bubbles. Figure 2.2a illustrates a dissolved air flotation system. Induced air flotation uses mechanical or diffused air aeration to produce bubbles with 500 to 1000 micron diameters. An induced air flotation system is shown in Figure 2.2b. In either case, chemical coagulants and/or polyelectrolytes may be used to effect particle size growth prior to aeration, thereby increasing particle rise velocity and improving separation. Surfactants may be used as conditioning agents to change the surface properties of the particles so that air bubbles will more readily adhere.

In all types of flotation, the design includes appropriate equipment for skimming and removal of the oily or sludge-like float from the surface of the treated wastestream.

Applicability to the Treatment of Hazardous Waste

Flotation is an appropriate treatment technology where oil or light solids must be separated from a hazardous liquid waste. Flotation is frequently used for separation of oil from oily aqueous waste. This is an important application because many states regulate waste oil as a hazardous waste.

A recent technical paper discusses uses of DAF for treatment of 50 gpm of industrial rinsewater at a plant that manufactures latex and adhesives. This wastewater contains 1 to 4 percent organic solids. Upstream of DAF, the waste is prepared for flotation by equalization, pH adjustment for emulsion-breaking, coagulation with alum, and flocculation with polyelectrolytes. The DAF unit is operated in the pressurized

recycle mode. A float containing 4-6 percent solids is skimmed off and subsequently dewatered to a 20-25 percent solids sludge which is landfilled. The clarified aqueous effluent from the DAF unit contains only 30 mg/l suspended solids.

Environmental Considerations

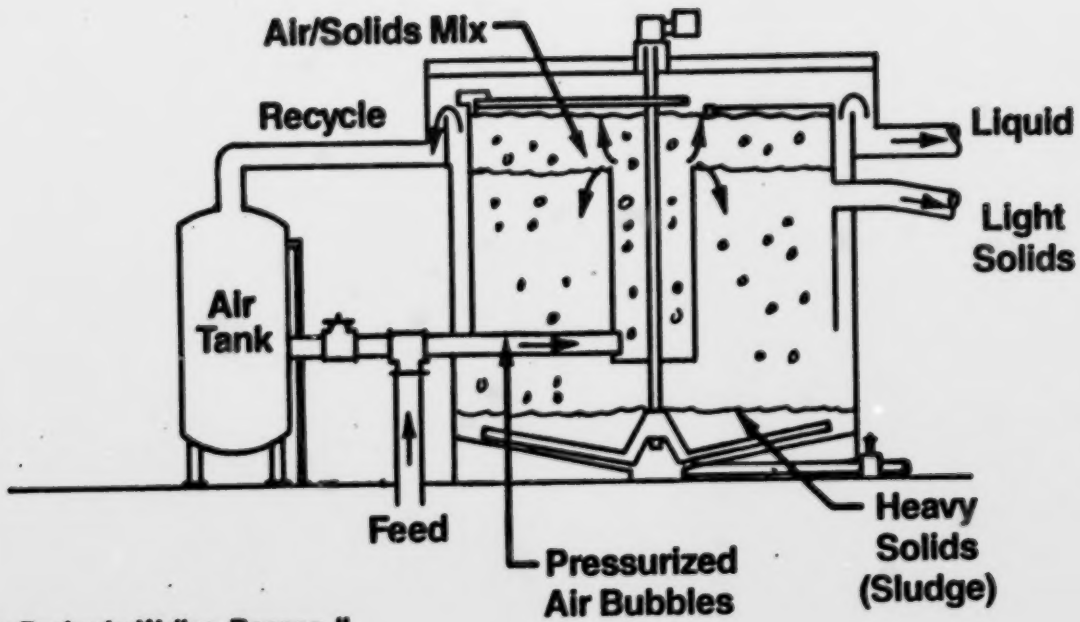
Every flotation process produces:

1. a liquid effluent which may require further treatment before it can be discharged to a municipal sewer or to surface water.

2. a skimmed residual. In the case of simple flotation, the skimmed free oil may be recovered for its fuel value. Air flotation processes are more likely to produce a sludge-like residue that is not economically recoverable and would typically be incinerated or landfilled.

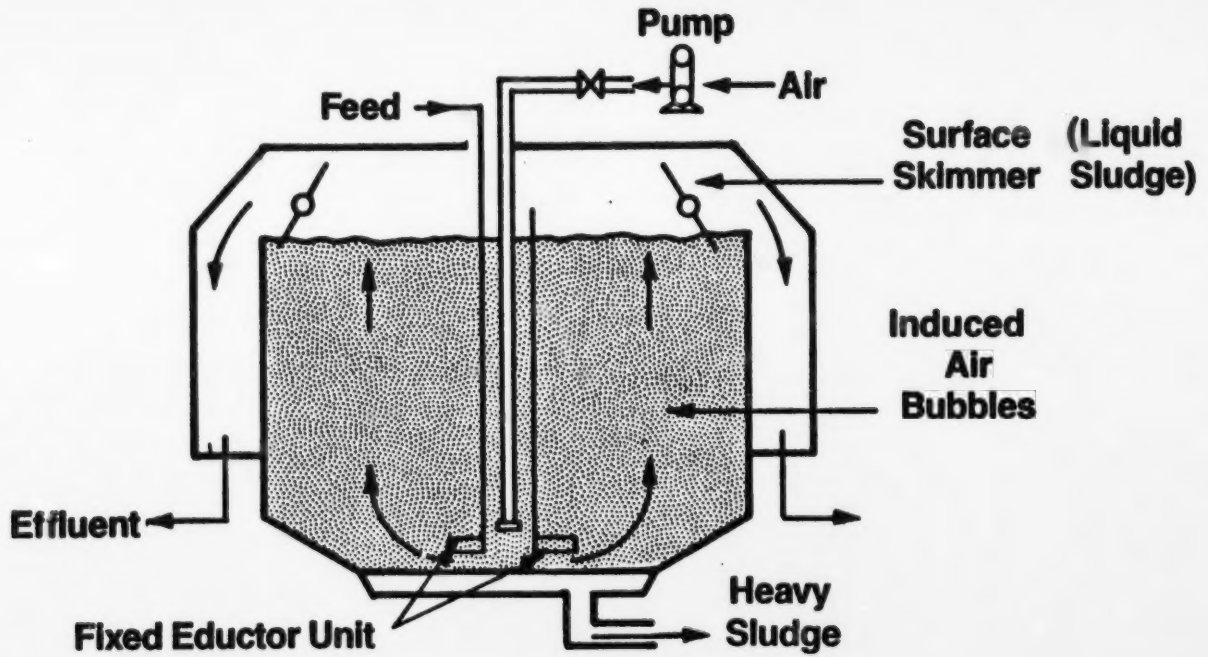
In addition, there is the potential for atmospheric release of volatile chemicals from open-topped flotation tanks due to air stripping.

FIGURE 2.2a
RECYCLE FLOW DAF SYSTEM



Source: Peabody-Welles, Roscoe, IL

FIGURE 2.2b
INDUCED AIR FLOTATION



Source: U.S. Filter, Whittier, California

SECTION 2.3

CENTRIFUGATION

Process Description

Centrifugation is a physical process which uses centrifugal forces created in a stationary vessel to separate immiscible components based on their density. The centrifugal force is created by an internal piece of equipment, such as a bowl, basket, or disk, that is spun at a high speed. The centrifugal force causes the components with greater density to migrate to the outer portion of the spinning mechanism. Centrifugal forces in centrifugation are similar to gravitational forces in sedimentation except that the centrifugal forces are thousands of times stronger than gravitational forces.

There are three major types of centrifuges which may be classified by their rotating device - bowl, basket, and disk. The continuous discharge bowl centrifuge has a solid tubular bowl with a tapered end where final dewatering takes place. Inside the bowl is a rotating scroll that spins in the same direction as the bowl at a slightly slower or higher speed to remove the separated solids. A schematic of the continuous solid bowl centrifuge is presented on Figure 2.3a.

Similar to the bowl-type centrifuge but with a diameter larger than its working length is the solid basket type machine. There are two types of basket centrifuges and they are distinguished by the axis upon which the basket rotates. The less common basket centrifuge, which spins about a horizontal axis, is a batch centrifuge which requires stopping the centrifuge and cleaning the basket of sludge. The other basket centrifuge rotates on a vertical axis. In this centrifuge the liquid (centrate) is forced to the top lip of the basket where it flows over a weir and is removed. The solids are forced to the basket surface forming a cake. The cake is removed by slowing the basket rotation and advancing a plow or other device into the cake forcing the collected solids to fall out the bottom of the basket. A basket centrifuge is shown in Figure 2.3b.

The disc centrifuge utilizes angled discs mounted on a vertical axis. The feed to this centrifuge is distributed into layers of roughly 0.05 inches thick between the conical discs. This separation of the feed increases the ability of the centrifuge to separate the solids. The solid particles settle through these channels to the underside of the disc and eventually to a sludge compaction zone.

Typical overall dimensions for bowl centrifuges range from two to six feet in height by six to twelve feet in length by three to six feet in width. The actual inside diameter of the bowl can range from less than one foot to over two feet. These operating dimensions are appropriate for an influent slurry rate of between 8 gpm and 800 gpm.

Basket centrifuges have actual basket dimensions that typically range from one foot in diameter to four feet in diameter by two feet to three feet in depth. Basket centrifuges can treat wastewater flow rates of between 20 and 80 gpm.

Disc-type centrifuges have typical overall dimensions of one to three feet in diameter by four to eight feet in length. These centrifuges have influent flow rate capacities ranging from 5 gpm to 500 gpm.

Applicability to the Treatment of Hazardous Wastes

Hazardous waste treatment applications for centrifuges include dewatering of sludge and separation of oil from water and solids. Centrifuges are generally better suited than vacuum filters for dewatering of sticky or gelatinous sludges. Disc-type centrifuges can be used to separate a three component mixture such as oil/water/solids. In this application, the oil (which in most instances is the least dense component) moves to the center of the centrifuge and is discharged through an upper spout while the water travels in the opposite direction and is discharged from a lower spout. The solids are collected at the outer periphery of the bowl and are automatically or manually removed. This application is very common in the metal working industry to recover oils or coolants for reuse, and in the oil refining industry for slop oil recovery.

Centrifugal operations are generally limited to the dewatering of sludges and the separation of oil from water. Centrifuges can not generally be used for clarification because centrifugation removes large quantities of solid material but also fails to capture much of the solids. Typically 80-90 percent of the influent solid material is recovered. Recovery may be improved if a filter paper or cloth is ued to line the basket.

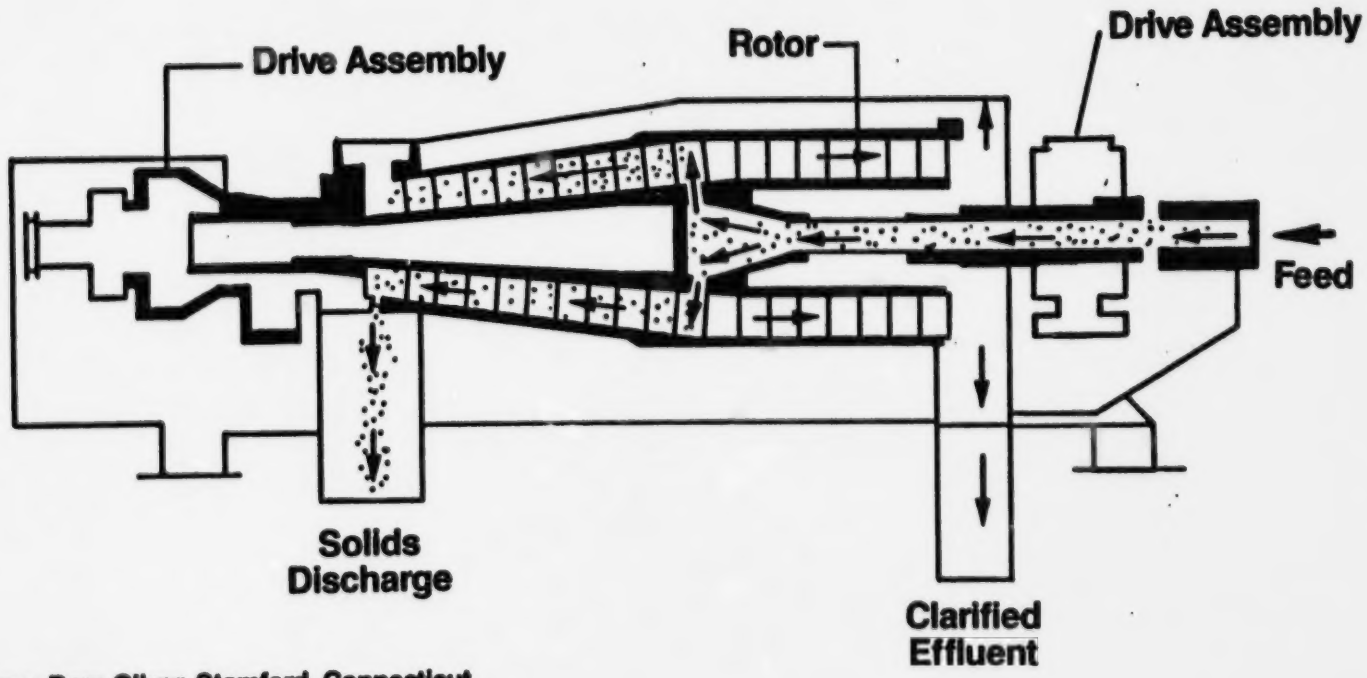
At a commercial hazardous waste treatment facility which treats aqueous wastes in 500 gallon batches, a horizontal perforated basket centrifuge with a rotational speed of 850 RPM is used to separate precipitated metals from treated wastewater. The basket is lined with a filter paper. Effluent is sewered. The high solids sludge may be sent to a metal reclaimer or landfilled.

Environmental Considerations

The centrate after sludge dewatering by centrifugation contains 10 to 15 percent of the feed solids and must be recycled for treatment. A sludge cake containing 10-20 percent solids can be produced by centrifugation of metal hydroxide sludges. In phase separation applications, the water portion contains significant oil and/or solids and must be recycled for treatment.

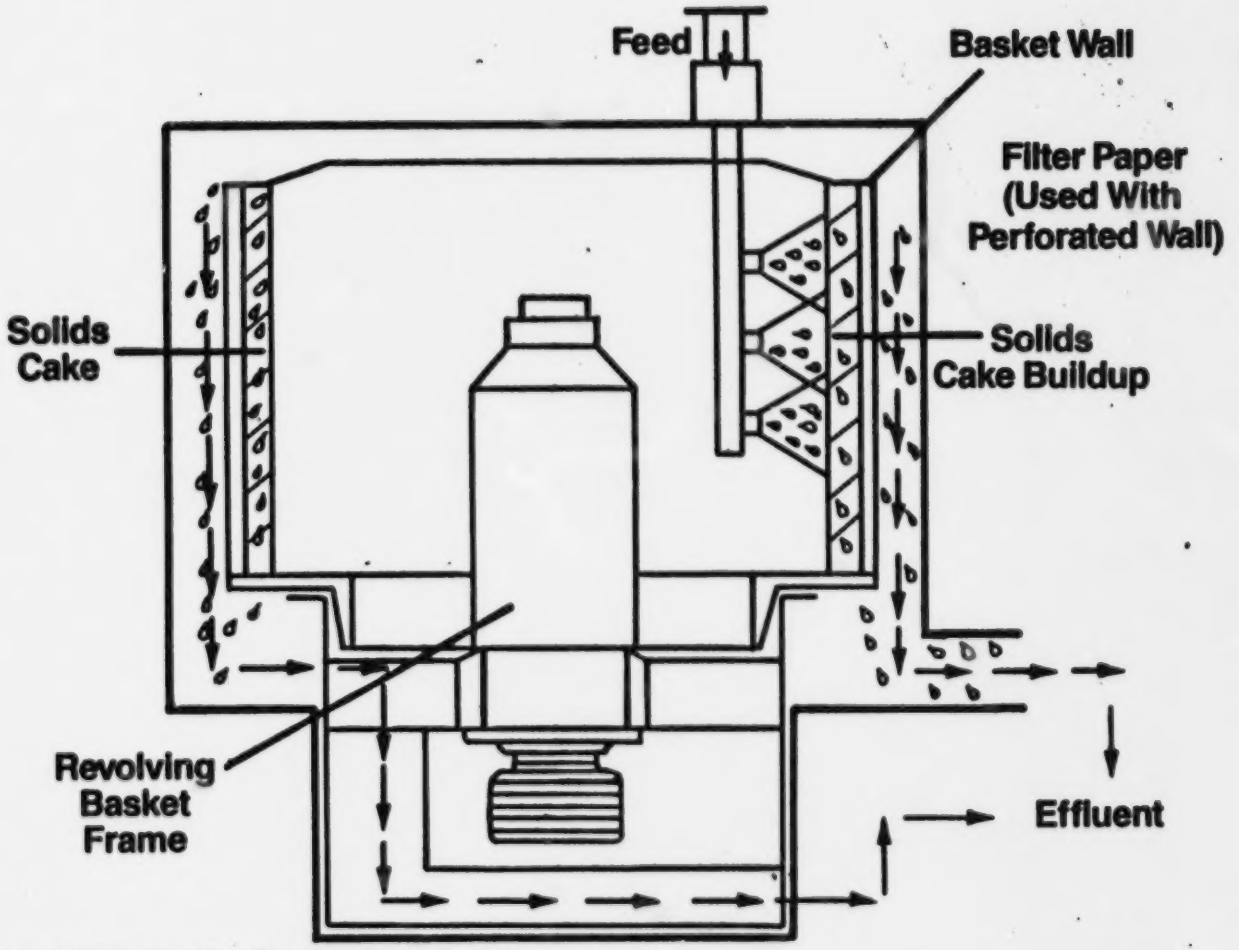
This is also the potential for emission of volatile chemicals from open topped basket centrifuges.

FIGURE 2.3a
SOLID BOWL CENTRIFUGE



Source: Dorr-Oliver, Stamford, Connecticut

FIGURE 2.3b
BASKET CENTRIFUGE



Source: Western States Machine Co., Hamilton, Ontario

SECTION 2.4

GRANULAR MEDIA FILTRATION

Process Description

Granular media filtration is the removal of suspended solids from a fluid by passage of the fluid through a bed of granular material. Several mechanisms are involved in the removal of suspended solids by granular media filtration. They include straining, physical adsorption and coagulation-flocculation. A granular media filter therefore can remove particles much smaller than the void size of the filter media.

The most efficient granular media filter utilizes the entire bed depth, not just the surface. Accordingly, the ideal bed would be graded from the largest to the smallest media size in the direction of flow. Unfortunately, in the usual downflow filter configuration backwashing to remove accumulated solids tends to distribute the media in the reverse order, with the smaller grain sizes on top. Two methods have been used to approach the ideal - upflow filtration and multi-media filtration using two or more materials with different densities. Materials most commonly used for multi-media filters are anthracite, sand and garnet.

Filters may be open top with gravity feed, or enclosed in a pressurized vessel. The range of configurations available include many proprietary designs related primarily to improvements in the backwashing operation. Figures 2.4 illustrates a granular media filter.

Filtration rates range from two gpm/sf for shallow beds of fine sand to over 15 gpm/sf for deep bed filters using coarse sand or multiple media beds. Vessels are from 2-1/2 to 20 feet in diameter, with media depth of 1-1/2 to over 15 feet.

Applicability to Hazardous Waste Treatment

Granular media filtration would typically be used after gravity separation processes, for:

1. additional removal of suspended solids and oils prior to other treatment processes

2. polishing of treated wastes to reduce suspended solids and associated contaminants to low levels.

Pretreatment by filtration would be appropriate for membrane separation processes, ion-exchange, and carbon adsorption in order to prevent plugging or overloading of these processes. In

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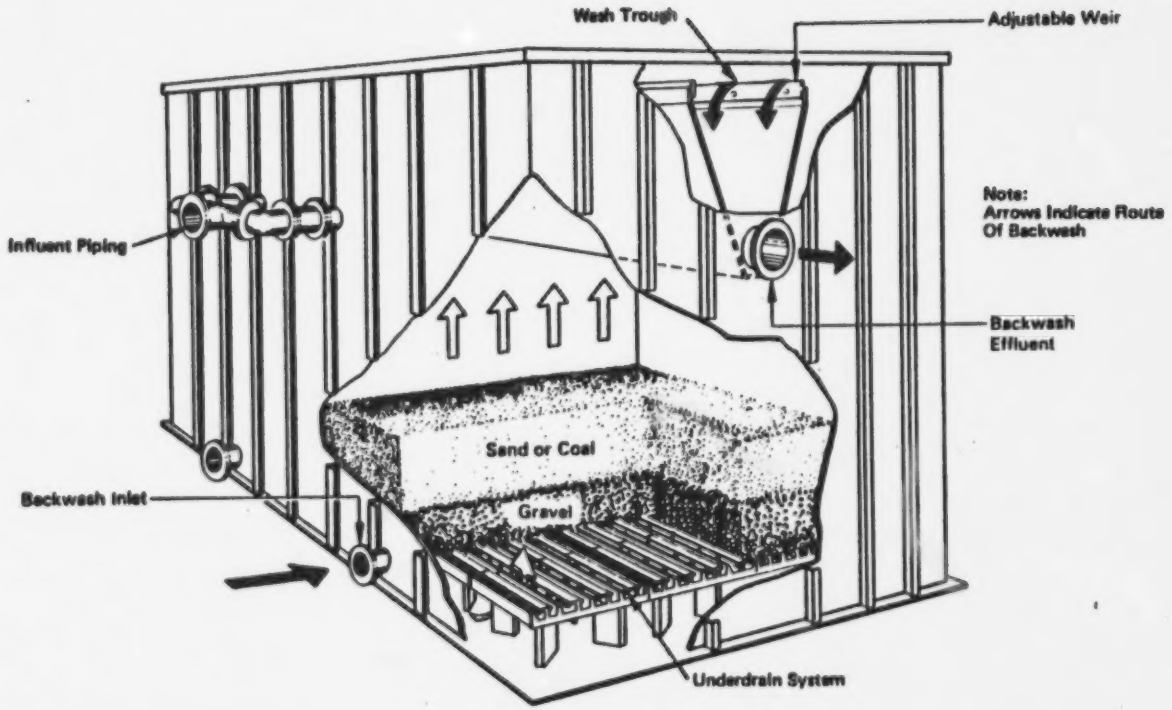
heavy metals removal by precipitation, very low metal limits apply to the treated effluent that is discharged to surface water or pubicly owned treatment works. Filtration of settled waste is often required to remove undissolved heavy metals which occur as suspended solids to ensure meeting effluent quality requirements.

Granular media filtration should be preceded by gravity separation or other pretreatment processes for suspended solids concentration greater than about 100 mg/l. Otherwise, premature plugging and excessive backwashing will occur.

Environmental Considerations

Accumulated solids and oils are removed from the granular media bed by backflushing with water, sometimes in combination with air. The backwash water is either recycled to a clarifier or treated separately for concentration and dewatering of the solids.



SOURCE: INFILCO DEGREMONT, INC

FIGURE 2.4 PACKAGED GRANULAR MEDIA GRAVITY FILTER

SECTION 2.5

VACUUM FILTRATION

Process Description

Vacuum filtration is the dewatering of sludges under negative pressure, and generally is employed to dewater sludges produced from precipitation and sedimentation processes. A typical vacuum filter is a mechanically supported cylindrical rotating drum covered by a filter medium made of cloth, coil springs, or a wire-mesh fabric. As it rotates slowly, but continuously, through a sludge vat, sludge in contact with the drum is subjected to a vacuum exerted through internal pressurized pipes. Water is drawn through the filter media, leaves behind solids on the media surface, and is discharged as clean filtrate from an exit port. The solids are dislodged by positive pressure from the piping system and the action of a mechanical scraper applied as drum sections become exposed. The filter media is then washed to remove remaining solids deposits.

Sludges are usually chemically conditioned with poly-electrolytes or lime, and/or ferric chloride prior to vacuum filtering to decrease clogging and reduce solids concentrations in the filtrate. The filter media may be coated with various precoat materials, such as diatomaceous earth, which traps finer particles and increases solids removal. A representative rotary vacuum filter is shown in Figure 2.5.

Applicability to the Treatment of Hazardous Waste

Vacuum filters are very common sludge dewatering devices for treatment of hazardous wastes from a number of manufacturing industries such as the organic and inorganic chemicals production and paint and dye manufacture. Dewatering of metal hydroxides from plating and finishing waste treatment by vacuum filtration is also commonplace.

Potentially banned wastes which are treatable with this technology include:

- metals and cyanides bound up in hydroxide sludges
- organic and inorganic chemical sludges

While vacuum filtration is not a detoxification or destruction technology, the process is important in reducing the volume of hazardous sludge that must be managed.

Vacuum filtration is ideally applicable to sludges of a solids concentration between 5 to 10 percent, therefore it is often preceded by thickening. Lower solids concentration require an excessively large vacuum filter size and time of operation, higher concentrations will be viscous and difficult to handle. A filtrate with solids concentration from 100 to 5,000 mg/l or more is generated which must be treated prior to discharge (Kiang and Metry, 1982).

Most sludges can be dewatered to solids concentrations between 20-50 percent. Metal hydroxide sludges are dewaterable usually to at least 30 percent solids and 40 percent solids or better is not uncommon.

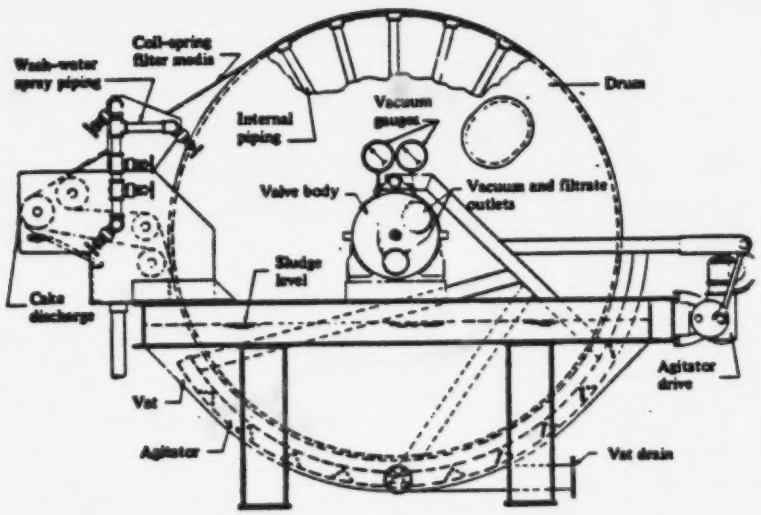
The applicability of vacuum filtration for the management of hazardous wastes was confirmed during one of the visits made to commercial facilties as part of this EPA sponsored study. This commercial establishment employed neutralization and precipitation for metals removal. The sludge produced from the metals precipitation process was thickened on a clarifier. The filter cake produced from the vacuum filter was typically comprised of 25 percent solids, thereby reducing the metal precipitate sludge volume requiring disposal.

Environmental Considerations

Similar to other liquid-solid separation processes, vacuum filtration produces several residuals that must be properly managed. These include;

1. Dewatered sludge cake
2. Filtrate
3. Drum washings
4. Vapors.

Depending on the chemical composition of the dewatered sludge, several management options are available including reuse, recovery and solidification/fixation. The filtrate can be recycled back to the treatment system, discharged, or used for process water depending upon its characteristics. Drum washings are normally recycled back to the treatment system. The negative pressure occurring during part of the vacuum filtration cycle can result in the release of volatile components from the sludge. Data is needed for all four of these residuals in order to determine appropriate management options.



SOURCE: CLARK, ET. AL. 1977

FIGURE 2.5 TYPICAL VACUUM FILTER

SECTION 2.6

CHAMBER PRESSURE FILTRATION

Process Description

Chamber pressure filtration is the dewatering of sludges in mechanical filtration chambers which operate in parallel under pressures typically about 100-200 psi. Chamber pressure filters include pressure leaf filters, tube element filters, horizontal plate filters, and plate-and-frame or pressure filters. The last is most representative of chamber pressure filters, is in widest use, and will be the focus of this discussion.

A pressure filter (also called filter press) consists of a collection of cloth covered plates arranged in parallel, held vertically within a frame, and pressed together by a hydraulic cylinder. (Figure 2.4). Sludge is pumped under pressure into the chambers between the plates, the plates are compressed, and water exits through the filter cloth. The concentrated solids left behind in the chamber are periodically removed; the filtrate is usually clear and dischargeable without further treatment. Precoating the filter cloth with diatamaceous earth can prevent clogging of its pores, and often the sludge is chemically conditioned to improve filterability by consolidating fine particles.

Dewatering of flocculated or sticky sludges by pressure filtration can produce cake densities in the range of 40-50% dry solids after a 1-2 hour batch pressure cycle.

Applicability to the Treatment of Hazardous Wastes

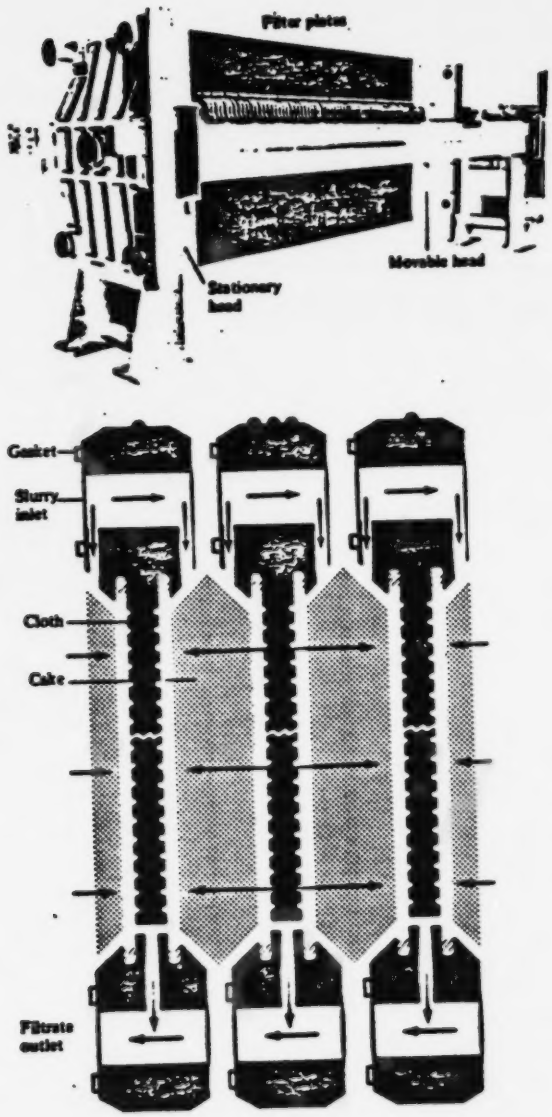
Pressure filtration is well suited to dewatering sludges with a flocculated or adhesive-like nature, such as metal hydroxide sludges. It dewaters such sludges to a higher solids concentration than is achievable with a vacuum filter, though at a somewhat higher capital and operating cost.

At one of the commercial hazardous waste management facilities surveyed, a plate and frame filter press was being used to dewater metal hydroxide sludges. Various drummed and bulk liquid aqueous wastes and mixed aqueous-organic liquid wastes were adjusted to pH 11 with lime. The entire process stream containing the mixed-metal hydroxide sludge was subjected to a plate and frame filter press. The 45 percent solids filter cake produced was landfilled, while the filtrate was neutralized to pH 6-7 with hydrochloric acid, and subjected to treatment with GAC prior to discharge to the municipal sewer.

The applications of chamber pressure filtration are limited to systems that can tolerate batch operation. Where unit operations, used to treat hazardous wastes are operated in a continuous mode, sufficient sludge holding capacity ahead of the filter must be provided.

Environmental Considerations

The use of chamber pressure filtration reduces the volume of sludge requiring disposal and reduces the associated disposal costs. The residuals that must be properly managed, and for which data needs have been identified, include the filter cake, the filtrate, and any filter washings. As mentioned in the previous section, at least one commercial hazardous waste facility is treating the filtrate to effect neutralization and organics removal, while the filter cake is being landfilled. Alternatively, the filtrate can be recycled to the treatment process.



Reproduced from best available copy.

FIGURE 2.6 TYPICAL FILTER PRESS UNIT AND FILTER CHAMBER ASSEMBLY

SECTION 2.7

BELT FILTER PRESS

Process Description

Belt filter presses employ single or double moving belts to continuously dewater sludges through gravity and pressure stages (Figure 2.7). Chemical flocculation is important for consistent solids capture. Most units include a flocculating mixer and polymers are usually added from a bulk processing system. The conditioned sludge is introduced onto a gravity drainage section. This section removes free water, sometimes with a vacuum assist, and increases feed solids concentration which improves filter performance.

Sludge is then squeezed through a series of rollers in the pressure stage. The rollers apply increasing pressure and shear force as the sludge moves through the press. Cake discharge is accomplished by a discharge roller and blade. A high pressure water spray is required to clean the belts after cake discharge.

Sludge feed is usually between 0.5 and 10 percent solids, and should be maximized to improve performance. Dry solids loading rates typical vary between 600 and 1500 lb/hr/meter of belt width. Presses are generally available in sizes ranging from 0.5 to 3.5 meters in width though the 1.5 to 2.5 meter width currently appears to be most practical. Solids capture for biological sludge is usually better than 90 percent resulting in cake solids of 12 to 44 percent with dry polymer dosages of 2 to 20 lb/ton. Belt speed, tension and type are important operating parameters. The flow rate for belt washing is usually 50 to 100 percent of the sludge feed flow rate, and it is applied at 100 psi or more. The wash waters are usually combined with the filtrate resulting in suspended solids concentrations of 500 to 1000 mg/l, which are returned to the treatment process.

Applicability to the Treatment of Hazardous Waste

Belt filter presses have recently gained popularity dewatering biological and industrial sludges because of design changes which have resulted in improved performance. Continuous operation yielding fairly high solids content cake combined with low capital costs have made this a cost effective dewatering process. It has been used to dewater metal hydroxide sludges and is being integrated into many industrial treatment processes. Other industrial applications include textile waste sludges, deinking sludges, bauxite clays, silicon wastes, coke water slurries, lime fluoride wastes, primary paper sludges, chemically flocculated oil and waste sludges, aluminum oxide slurries, and pharmaceutical waste sludges. Application usually

requires laboratory testing of sludge samples to determine applicability and polymer dosages. Pilot tests may be conducted to measure performance and provide design data.

Large polymer dosages may be required for effective operation. Operation and belt parameters are optimized for sludge conditions. Sludges with highly varying conditions may require large holding capacity and blending. Different sludges may require dewatering separately under different operating conditions.

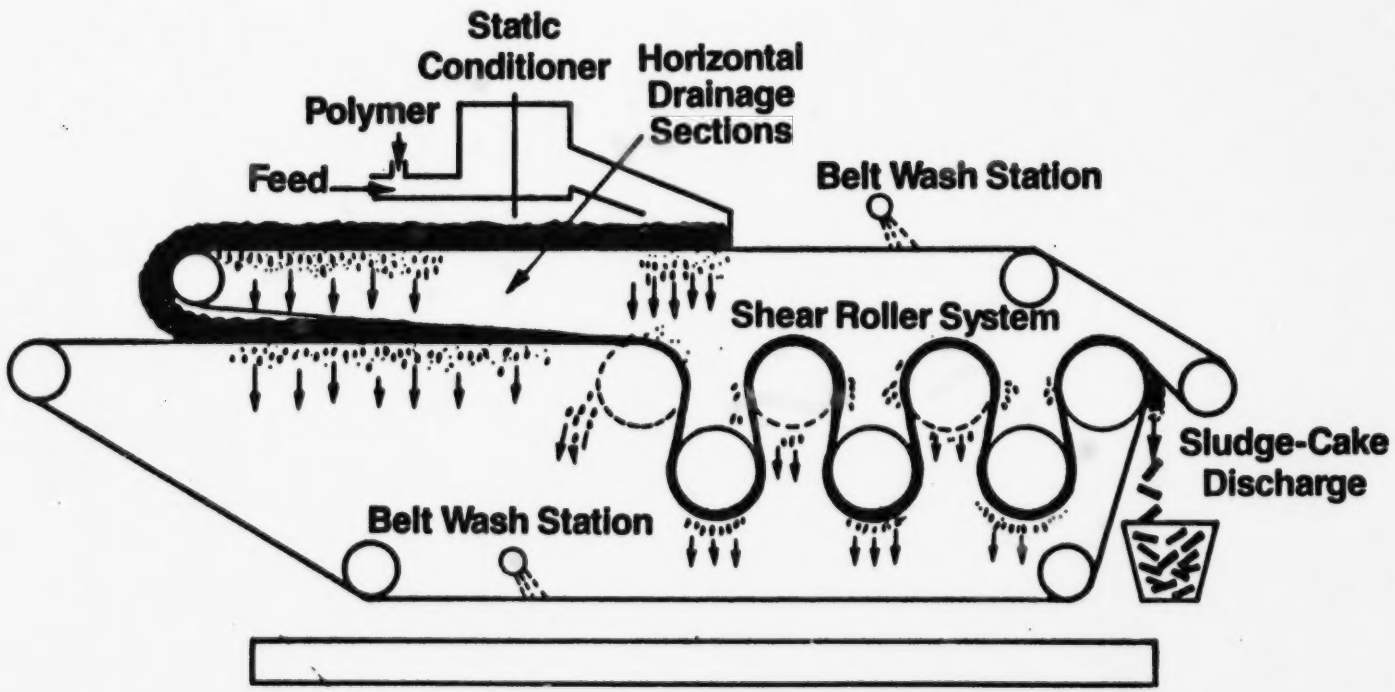
At one of the commercial hazardous waste treatment facilities visited, a 1.5 meter wide continuous belt filter press was being used to dewater mixed metal hydroxide and sulfide sludges.

The raw sludge from the thickener contained 6-8 percent solids and was preconditioned by adding polymer. The filter cake from the belt filter press, containing 27-32 percent solids, underwent solidification/fixation with quicklime. The filtrate from the press was being returned to the treatment process.

Environmental Considerations

Belt filter presses may provide a lower cost method of dewatering sludges. Reductions in volume will result in reduced disposal requirements and costs. Polymer addition and reduction of moisture content will improve sludge combustion characteristics. The filtrate and belt wash waters contain suspended and dissolved solids which must be recycled for treatment. The filter cake may have to be treated further prior to disposal. Data are needed for all of these residuals in order to select the appropriate management options.

FIGURE 2.7
BELT-TYPE SLUDGE PRESS



Source: Ashbrook-Simon-Hartley, Houston, Texas

SECTION 2.8

EVAPORATION

Process Description

Evaporation is the vaporization of liquid from a solution, slurry, or sludge through the application of an energy source. This process is practical when one component is minimally volatile. In some instances, the liquid to be evaporated is water and the technology is used to concentrate the nonvolatile component. In other cases, evaporation is used to separate solvent from nonvolatile solids, oil, or water as a first step in the reclamation of waste solvent.

There are several process variations on the technology for evaporation. The simplest process involves evaporation ponds using solar energy to evaporate water and other volatiles. This technology is appropriate when there is enough land available to provide sufficient surface area for the evaporation process.

The other processes use a heated vessel to evaporate some of the volatile fraction thereby concentrating the nonvolatile bottoms. The first of these processes is the single-effect evaporator shown in Figure 2.8. These units usually use steam to heat the liquid to its boiling temperature. The steam is passed through a steam coil or jacket. The vapors produced by the boiling liquid are drawn off and condensed. The concentrated liquid is pumped out of the bottom of the vessel. This process requires about 1200 BTU/lb of water evaporated. The second process is a series of single-effect evaporators in which the vapor from the first evaporator is used as the heat source to boil the liquid in the second evaporator. Boiling is accomplished by operating the second evaporator at a lower pressure than the first. This process can continue for several evaporators as shown in Figure 2.8. This process is called multiple effect evaporation and depending on the number of effects may use only 200 BTU/lb of water evaporated.

The third process is called vapor recompression evaporation. This process uses steam to initially boil the liquid but once vapor is produced it is compressed to a higher pressure and temperature. The compressed vapor is then directed to the jacketed side of the evaporator instead of using more steam and is used as the heat source to vaporize more liquid. This process requires as little as 40 BTU/lb of water evaporated.

The standard vessels used for water evaporation can vary in size from one gallon capacity to one thousand gallons capacity, although larger custom units are designed and manufactured.

Single-effect mechanically-agitated or wiped thin film evaporators are used for recovery of volatile organic solvents from waste solvent streams that may contain high concentrations of solids or nonvolatile oil and grease. Waste solvent is pumped into the top of a jacketed vessel. Inside the vessel, close clearance rotating blades continuously spread the feed over the hot walls. The solvent boils and overhead vapors rise out the top of the vessel into a condenser. Thin film evaporators may be operated under vacuum so that solvents can be vaporized at temperatures below their normal boiling points. The recovered solvent may be acceptable for reuse or may require further purification by distillation. The bottoms sludge, typically containing 30-50 percent solids, may be incinerated or landfilled.

Applicability to Treatment of Hazardous Waste

Evaporation can be used to treat a wide range of hazardous waste streams. In industries which generate large volumes of aqueous wastes with dilute hazardous constituents, evaporation can be used to concentrate the waste stream for additional treatment or shipment off site.

Solar evaporation is used to concentrate waste streams such as metal hydroxide slurries, corrosives, acids, alkalis, aqueous streams contaminated with organics and cyanide wastes with less than 100 ppm cyanide. One particular site utilizes 250 acres of surface ponds for holding aqueous wastes and rainwater runoff. This site also uses sprays to enhance evaporation and estimates that 12 million gallons of water is evaporated per month.

Thin-film evaporation is used at another site as the first step in waste solvent purification. The vapor stream is condensed and pumped to a distillation column for further purification. Evaporation is performed to remove solids that would otherwise foul the distillation equipment. This facility uses two "VOTATOR" thin-film evaporators manufactured by Cherry-Burrel, ANCO-VOTATOR division. One unit contains 50 ft^2 of heat transfer area and produces 15 gpm of overhead product while the other unit contains 60 ft^2 and produces 20 gpm overhead product.

Vapor recompression is used in many industries. One particular company uses this process to concentrate rinse water from electroplating copper foil. The waste contains copper sulfate and zinc sulfate. The evaporator operates at 150 deg. F and 24 in. Hg vacuum, concentrates the solids ten times above

influent concentration and processes 17 gpm. The concentrate is then used as plating solution make-up.

Environmental Considerations

Evaporation is an expensive technology, both in terms of capital costs and operating costs. Solar evaporation is often less expensive, but the use of land for evaporation is expensive and in addition lagoons used for solar evaporation often require bottom liners to prevent the migration of hazardous constituents into the groundwater and will need to meet other pertinent federal and state environmental regulations. For instance, the state of California requires that a solar evaporation pond must be emptied once every 12 months to be considered as a treatment process rather than a disposal practice.

Mechanical evaporation produces a condensate and a bottoms stream one or both of which may require further processing or disposal.

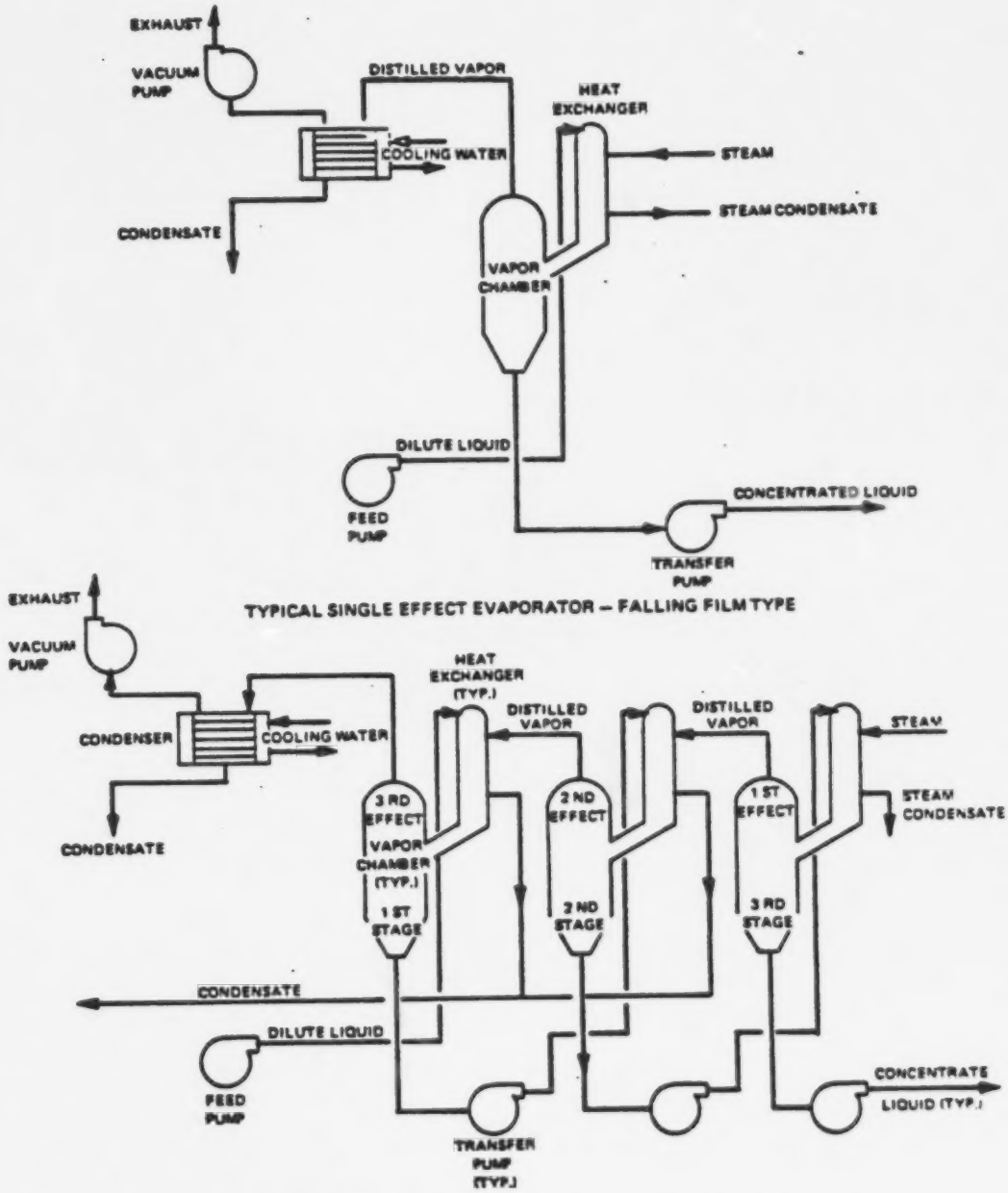


FIGURE 2.8 SCHEMATIC OF SINGLE AND MULTIPLE EFFECT EVAPORATORES (METCALF & EDDY, 1979)

SECTION 2.9

DISTILLATION

Process Description

Distillation is the vaporization of one or more, usually concentrated, volatile components out of liquid solution. Individual components vaporize in order of their volatility so that relatively pure products result upon condensation. Organic products are purified or volatile chemicals are recovered. Non-volatile residues of varying solids concentration remain behind in the feed.

Distilling is accomplished in vessels ranging up to 40 feet in diameter and 200 feet tall. Each are equipped with a heat source such as a steam jacket or heating coil which boils the liquid and drives off the desired chemical. A condenser converts the vapor to liquid which is collected in an accumulator. The capacity of a given unit is a function of the waste being processed, purity requirements, reflux ratio and heat input.

Distillation can occur as a batch or continuous process and under pressures ranging from near vacuum to several atmospheres. Fractional distillation is a continuous process which employs fixed trays for large scale units or packing materials for small scale units. Tray (also called plates) configurations vary, with representative examples including bubble cap tray or simple perforated horizontal plate. Feed liquids enter above the plates or packing and volatile components are vaporized by contact with rising vapor from the boiling liquid below. Fractionation of two or more volatiles can produce a series of vaporized fractions of different concentration. Figure 2.9a and 2.9b illustrate batch and fractional distillation, respectively (Kiang and Metry, 1982).

Steam distillation employs steam as the direct carrier of immiscible volatile compounds out of solution. Steam distillation operates on the principle (Dalton's law of partial pressures) that the total vapor pressure exerted upon heating when two or more immiscible liquids are involved, is equal to the sum of the vapor pressure of each liquid. A lower temperature (heat input) is thus necessary to achieve complete volatilization because less than the typical vapor pressure at which it boils must be reached, and distillation occurs below each of their true boiling points. Steam distilling under a vacuum (lower pressure) is also routinely performed to produce similar results.

Steam distilling of liquids is usually conducted in batch or semi-batch distillation equipment retrofitted to allow

bubbling of steam through the feed, or in multi-tray columns. Carrier steam and the recovered volatile compound(s) are condensed or redistilled if not and recovered separately. Units handling feedstock (e.g. inks, paints, forest products) from which polymerized materials or solid residues remain after steam distillation require removable vessel heating equipment to allow disposal of accumulated deposits. A steam distillation unit is shown in Figure 2.9c. (Kiang and Metry, 1982).

Distillation products approaching 100 percent purity are possible. Higher purities generally require increasingly higher capital and operating expense.

Applicability to Treatment of Hazardous Waste

Distillation is very useful in reclaiming spent solvents or purifying certain aqueous wastes.

One solvent recycler has eight batch distillation units each consisting of a reboiler and fractionating column. The reboilers range in size from 800 to 18,000 gallons. The columns have diameters ranging from 2 feet to 4 ft and heights ranging from 30 feet to 80 feet. These columns are equipped with bubble cap trays. All columns can operate with reflux rates ranging from zero to total reflux. These units are used to produce high purity solvent for reuse by the waste solvent generator. Solvents reclaimed at this facility include hydrocarbons, chlorinated hydrocarbons, ketones, and alcohols.

A second company operates two 500 gallon glass lined steam jacketed batch stills. Each column contains six feet of ceramic Raschig ring packing. The stills are operated without reflux and produce a relatively low purity product suitable for resale to marketers of compounds like lacquer thinner and windshield washer fluid. Waste solvents treated at this facility include acetone, chlorinated hydrocarbons, ethanol, IPA, MEK, toluene, xylene and mixed solvents.

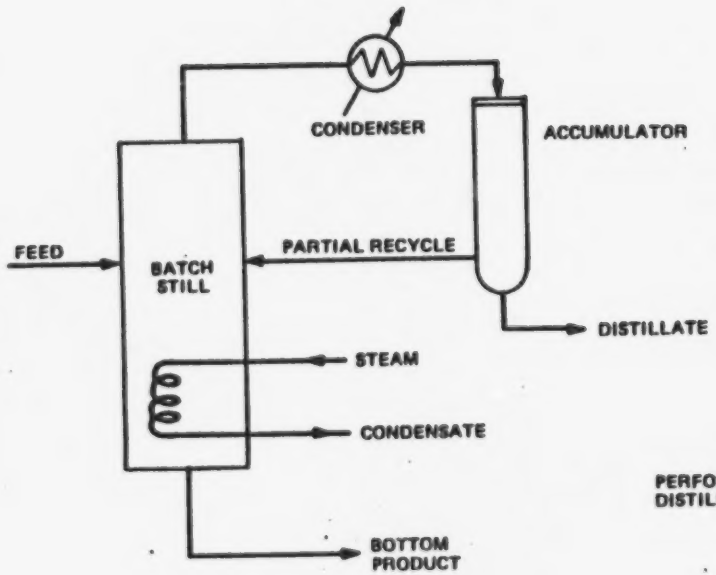
A third solvent reclaimer uses continuous, rather than batch, distillation. Batch distillation is generally preferred by commercial waste solvent reclaimers due to its flexibility and ease of operation. However, this firm was set up to handle large quantities of selected solvent waste streams on a toll basis, so continuous fractionation systems were designed to purify those specific wastes. The largest column at this facility is a 3-foot diameter, 110-foot tall tower with 48 valve trays. With this column, 99.9% pure freon is recovered from a waste solvent containing freon and 1,1,1 trichloroethane.

The limitations on the use of this process for hazardous waste are that the waste must have a very low solids concentration to prevent fouling of the equipment. Wastes that are

subject to producing tars or other fouling substances when heated may not be suitable for processing using distillation without prior treatment. Inorganic wastes would not be accommodated by this process.

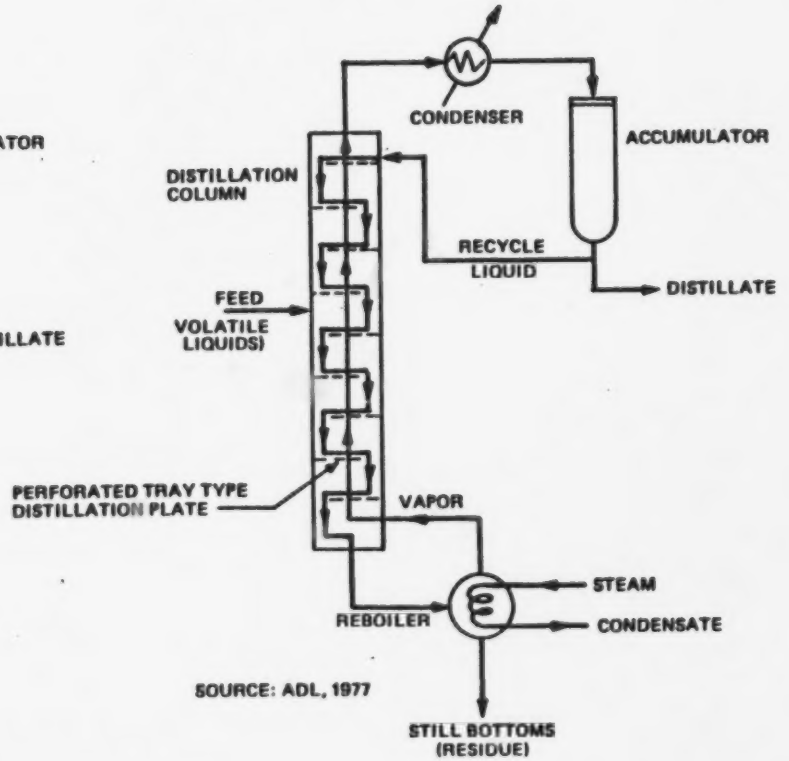
Environmental Considerations

Distillation produces a distillate fraction and a still bottoms fraction both of which may be resold as a raw material or require some other treatment or disposal depending on the material. Another residual produced by distillation is the tar and/or sludge buildup that occurs on the reboiler steam coils. This material must be periodically removed either by scraping and/or washing and is usually land-filled.



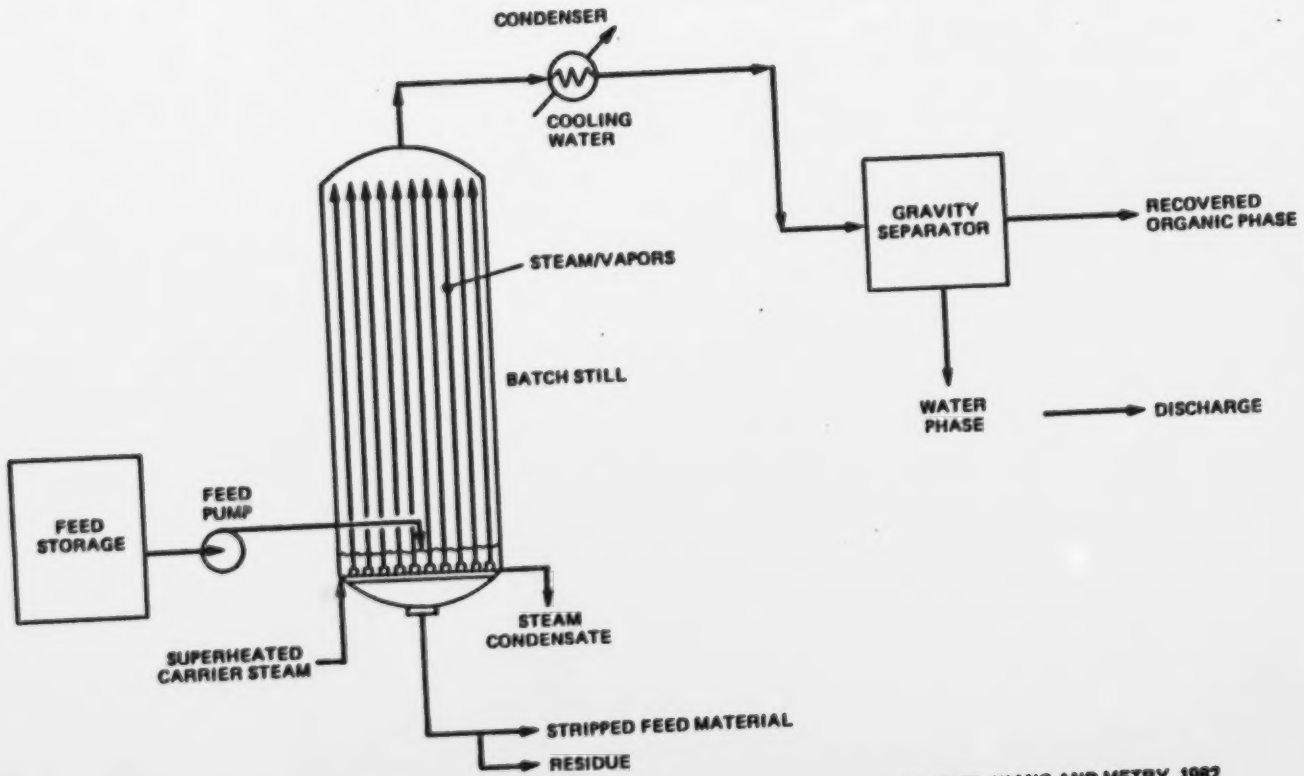
SOURCE: ADL, 1977

FIGURE 2.9a BATCH DISTILLATION



SOURCE: ADL, 1977

FIGURE 2.9b CONTINUOUS FRACTIONAL DISTILLATION



SOURCE: KIANG AND METRY, 1982

FIGURE 2.9c BATCH STEAM DISTILLATION

SECTION 2.10

ULTRAFILTRATION

Process Description

Ultrafiltration is a low pressure (10 to 150 psi) membrane process for separating high molecular weight dissolved materials or colloidal materials from liquids. The ultrafiltration membrane is a semi-permeable membrane, incorporated into membrane modules. The semi-permeable membrane is a thin selective layer (0.1 to 1.0 microns thick) and the membrane modules are typically made of a spongy material. The characteristics of the thin selective layer determine the size of the species passing through the membrane. Generally, low molecular weight species, such as salts, sugars, and most surfactants pass through the membrane. Ultrafiltration membranes can retain and concentrate organic solutes of 500 to 1,500 molecular weight.

The influent stream to the ultrafiltration membranes flows across the membrane surface at a high velocity. This characteristic of ultrafiltration differs from the perpendicular flow of most filtration methods. Because of the high velocity flow across the membrane in ultrafiltration, rather than flow through the membrane, fewer solids build up on the filter surface. This characteristic reduces the frequency of cleaning and allows the flux rate of the inlet stream to remain high.

Two streams are discharged from the ultrafiltration membrane, a concentrate stream, which contains the solute that does not pass through the membrane and a permeate stream, which has passed through the membrane. The permeate, which flows continuously from the UF unit, may be suitable for reuse or may be discharged. The concentrate stream is recycled to the process tank until some maximum concentration is achieved and the permeate flux rate declines. At this point the unit is shut down for cleaning. The concentrate may be recovered for reuse or for fuel value or may undergo further treatment or disposal.

Ultrafiltration devices range in size from 4 feet in length by 2 feet wide by 7 feet high to 32 feet in length by 10 feet wide by 14 feet high. These two respective devices can handle daily capacities from 50 gallons to 45,600 gallons. Flow through a UF system is typically 30 GPD/ft^2. The motor requirements for these devices range from 2 HP to 115 HP.

Ultrafiltration membranes can be flat sheet, tubular, spiral wound or hollow fiber. The two largest manufacturers of ultrafiltration membranes are Abcor and Romicon.

Pretreatment of the waste is often necessary before the wastewater passes through the ultrafiltration membrane. If pretreatment is not performed prior to ultrafiltration, the membranes will need to be cleaned much more often. The membranes normally need to be cleaned once a week. One pretreatment requirement for ultrafiltration is the removal of free oil and large amounts of suspended material. The equalization tank serves this purpose. The process tank serves as the concentrate holding tank.

An ultrafiltration schematic is presented in Figure 2.10a. A tubular membrane is shown in Figure 2.10b.

Applicability to the Treatment of Hazardous Waste

Ultrafiltration is a practical treatment technology for separating and, if desirable, recovering solutes of molecular weight greater than 500 to 1000 or suspended materials from an aqueous stream. Ultrafiltration is commonly used to remove emulsified oils, metals, and proteins from aqueous wastes.

Studies performed using ultrafiltration for removal of hazardous substances from aqueous wastes demonstrated 80 percent removal of TOC from a waste in which TNT accounted for 90 percent of the 20 ppm TOC concentration.

Ultrafiltration is often used to remove and recover emulsified oil from aqueous wastes. Typical metal working waste streams contain one to two percent emulsified oil. Ultrafiltration retains 99.9 percent of the emulsified oil and concentrates the oil to a concentration of 40 to 60 percent.

Environmental Considerations

If not recycled for reuse, the concentrate stream must eventually be disposed of. The spent membrane cleaning solution, typically a detergent, is sent to the equalization tank for treatment.

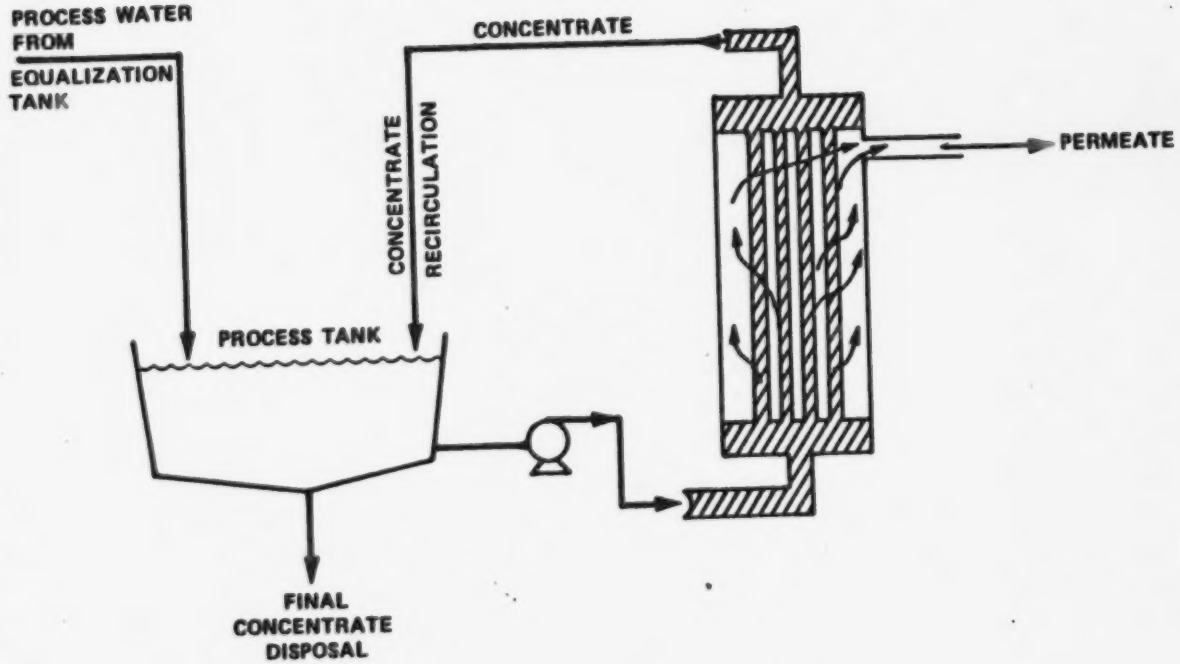


FIGURE 2.10a SCHEMATIC OF ULTRAFILTRATION

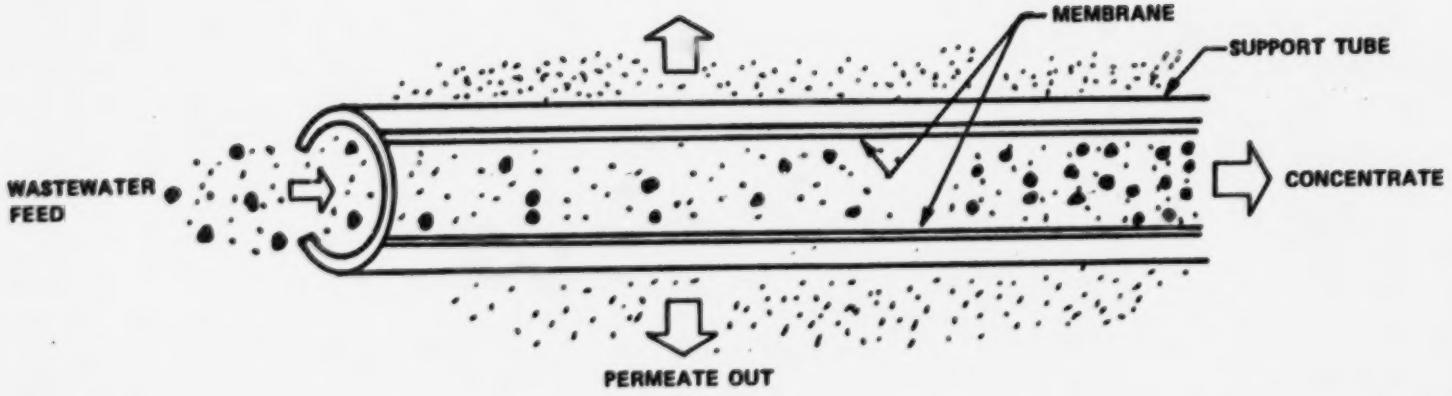


FIGURE 2.10b TUBULAR MEMBRANE – ULTRAFILTRATION

SECTION 2.11

REVERSE OSMOSIS

Process Description

Reverse osmosis is used to separate water from inorganic salts and some relatively high molecular weight organics. Pressure (typically 200 to 1200 psi) is used to force water from a solution through a semi-permeable barrier (membrane) which will pass only certain components of a solution (the permeate) but is impermeable to most dissolved solids (both inorganic and organic).

To prevent fouling, feed water must be pretreated to remove oxidizing materials including manganese and iron salts, to filter out particulates, to remove oil, greases and other film formers, and to destroy microorganisms. Feedwater temperature control may be necessary to keep the temperature within a specified range.

The basic components of a reverse osmosis unit are the membrane, a membrane support structure, a containing vessel, and a high pressure pump. Reverse osmosis units can be arranged either in parallel to provide adequate hydraulic capacity or in series to effect the desired degree of removal. A wide range of flows can be accomodated depending on the number of units used.

Commonly used membranes include tubular membranes, spiral-wound membranes, and hollow fiber membranes. The tubular membrane consists of a membrane which is inserted onto or into the surface of a porous tube. This type of membrane is primarily used for low volume operations. Spiral-wound devices usually use the membrane as a flat film. Sheets of the flat membrane film are separated by cloth and are spiral wound to form a cartridge. A number of spiral tubes are usually connected together and inserted into a pressure vessel. Hollow fiber membranes consist of millions of aramid or cellulose acetate fibers formed into a tube. Feed enters the center of one end of the tube. The other end of the tube is blocked off to prevent short circuiting. The hollow fiber device permits very large membrane areas per unit volume, making this the most compact device. Membrane materials include cellulose acetate, aromatic polyamides, and cross-linked polyethylenimines. The three types of commercial membranes are presented in Figure 2.11.

Applicability to the Treatment of Hazardous Waste

In the treatment of liquids containing hazardous wastes, reverse osmosis may be used for the removal of dissolved heavy metals and dissolved organics from aqueous wastes.

In one textile mill, virtually complete removal ($\geq$ 99 percent) was achieved for dimethyl phthalate, di-n-butyl phthalate, acenapthene, anthracene, and napthalene (EPA Treatability Manual, 1981) using a cellulose acetate membrane. In another textile mill study $\geq$ 99 percent removal was achieved for di-n-butyl phthalate, acenapthene, anthracene, fluoranthene and pyrene with a cellulose acetate membrane. In both of these cases influent concentrations were very low (0.4 to 55 mg/l). Generally, applications for reverse osmosis include removal and recovery of heavy metals from plating wastes, alcohols and dyes from textile wastes, and chromate from aqueous hazardous wastes. A summary of removal efficiencies of toxic pollutants from aqueous hazardous wastes is presented in Table 2-11. It should be noted that the variation in removal of certain compounds is significant when using different types of membranes.

Reverse osmosis has several limitations. This process is only applicable to aqueous liquid wastes. It is not usually applicable for use with initially highly concentrated solutions due to the increasingly high pressure required to overcome osmotic pressure as a solution becomes more concentrated. In addition, the feed stream must be compatible with the membrane. Incompatible compounds must be removed prior to treatment, or another process must be used. This can be a problem in the treatment of hazardous wastes since the chemical compatibility of many constituents in the waste streams may not be known.

Environmental Considerations

Reverse osmosis produces a highly concentrated reject stream. In some cases the constituent(s) of the reject stream may be recovered for reuse. However, often this stream requires additional treatment and must be disposed of.

TABLE 2.11. REVERSE OSMOSIS - REMOVAL EFFICIENCIES OF TOXIC COMPOUNDS

Chemical Classification	Chemical	Description of Study: Study Type	Waste Type	Influent Concentration	Effluent Conc. (1)	Removal Efficiency	Membrane Type (2)
Alcohols	Methanol	Batch (Lab)	Pure Compound	1000 ppm	786 ppm 297 ppm	21.4% 70.3%	CA C-PEI
Aliphatics	Acetone	Batch (Lab)	Pure Compound	1000 ppm	851 ppm 182 ppm	14.9% 81.8%	CA C-PEI
	Formaldehyde	Batch (Lab)	Pure Compound	1000 ppm	780 ppm 430 ppm	22% 57%	CA C-PEI
Amines	Aniline	Batch (Lab)	Pure Compound	1000 ppm	1000 ppm 170 ppm	0% 83%	CA C-PEI
Aromatics	Chlorobenzene	Lit. Review	Unknown	$\leq$ 360 ppm	0-11 ppm	97-100%	Unknown
	Dintrobenzene	Batch (Lab)	Pure Compound	30 ppm	28 ppm 5.7 ppm	7% 81%	CA C-PEI
	2,4-Dinitrophenylhydrazine	Batch (Lab)	Pure Compound	30 ppm	29 ppm 2.7 ppm	3% 91%	CA C-PEI
	Hexachlorobenzene	Lit. Review	Unknown	638 ppm	306 ppm	52%	Unknown
	Hydroquinone	Batch (Lab)	Pure Compound	1000 ppm	1000 ppm 200 ppm	0% 80%	CA C-PEI
		Lab Scale	Pure Compound	1000	0-200 ppm 1000 ppm	80-100% 0%	AP CA
Ethers	Bis (2-Chloroisopropyl) Ether	Batch (Lab)	Pure Compound	250 ppm	158 ppm 15 ppm	37% 94%	CA C-PEI
	Diethyl Ether	Batch (Lab)	Pure Compound	1000 ppm	905 ppm 100 ppm	9.5% 90%	CA C-PEI
	Ethyl Ether	Lab Scale	Pure Compound	1000 ppm	0-200 ppm	80-100%	AP
Heavy Metals	Barium	Batch	Pure Compound	0.75 ppm 0.85 ppm 9.15 ppm 7.05 ppm	< 0.10 ppm < 0.10 ppm 0.20 ppm < 0.10 ppm	> 86.7% > 88.2% 97.8% > 98.6%	CA CA CA CA
	Cadmium	Batch	Pure Compound	0.10 ppm 1.0 ppm	0.001 0.013	90% 98.7%	CA CA
	Chromic Acid	Lab, Continuous flow	Industrial	200 ppm	30	85%	PB

TABLE 2.11 (Continued). REVERSE OSMOSIS - REMOVAL EFFICIENCIES OF TOXIC COMPOUNDS

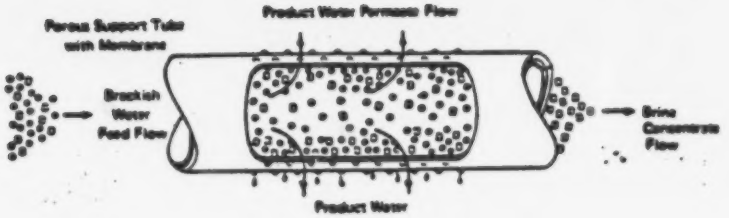
Chemical Classification	Chemical	Description of Study: Study Type	Waste Type	Influent Concentration	Effluent Conc. (1)	Removal Efficiency	Membrane Type (2)
Heavy Metals (cont'd)	Chromium	Batch	Pure Compound	12.5 ppm	0.25-1.12	91-98%	C-PEI
				0.94 ppm	0.028	97%	CA
				8.65 ppm	0.60	93%	CA
				9.35 ppm	1.4	85%	CA
	Copper	Batch	Pure Compound	12.5 ppm	0.0125	99.9%	C-PEI
				0.7 ppm	0.035	95%	CA
				6.5 ppm	0.065	99%	CA
	Lead	Batch	Pure Compound	12.5 ppm	0	100%	C-PEI
				0.95 ppm	0.005	99.5%	CA
				9.3 ppm	0.205	97.8%	CA
	Nickel	Batch	Pure Compound	12.5 ppm	0.87	93%	C-PEI, pH 8
					0.25	98%	C-PEI, pH 11
	Zinc	Batch	Pure Compound	12.5 ppm	0.375	97%	C-PEI, pH 8
					0	100%	C-PEI, pH 11
				10 ppm	0.14	98.6%	CA
				32.8 ppm	0.16	99.5%	CA
Pesticides	Aldrin	Batch	Pure Compound	142 µg	0 µg	100%	CA
					0 µg	100%	C-PEI
	Atrazine	Batch	Pure Compund	1102 µg	176 µg	84%	CA
					24 µg	97.8%	C-PEI
	Captan	Batch	Pure Compound	689 µg	8.3 µg	98.8%	CA
					0 µg	100%	C-PEI
	DDE	Batch	Pure Compound	69 µg	0 µg	100%	CA
					0 µg	100%	C-PEI
	DDT	Batch	Pure Compound	42 µg	0 µg	100%	CA
					0 µg	100%	C-PEI
	Diazinon	Batch	Pure Compound	474 µg	0 µg	100%	CA
					0 µg	100%	C-PEI
	Dieldrin	Batch	Pure Compound	321 µg	0.3 µg	99.9%	CA
					0 µg	100%	C-PEI
	Heptachlor	Batch	Pure Compound	145 µg	0 µg	100%	CA & C-PEI
	Heptachlorepoxide	Batch	Pure Compound	307 µg	0.6 µg	99.8%	CA & C-PEI

TABLE 2.11 (Continued). REVERSE OSMOSIS - REMOVAL EFFICIENCIES OF TOXIC COMPOUNDS

Chemical Classification	Chemical	Description of Study: Study Type	Waste Type	Influent Concentration	Effluent Conc. (1)	Removal Efficiency	Membrane Type (2)
Pesticide (cont'd)	Lindane	Batch	Pure Compound	506 µg	2.5 µg 5 µg	99.5% 99.0%	CA C-PEI
	Malathion	Batch	Pure Compound	1058 µg	8.5 µg 3.2 µg	99.2% 99.7%	CA C-PEI
	Methyl Parathion	Batch	Pure Compound	913 µg	3.6 µg	99.6%	CA & C-PEI
	Parathion	Batch	Pure Compound	747 µg	0.7 µg 1.5 µg	99.9% 99.8%	CA C-PEI
	Randox	Batch	Pure Compound	327 µg	91 µg 4.6 µg	72% 98.6%	CA C-PEI
	Trifluralin	Batch	Pure Compound	1579 µg	4.7 µg 0 µg	99.7% 100%	CA C-PEI
Phenols	2-Chlorophenol	Lit. Review	Unknown	-	-	66.3%	-
	Phenol	Batch	Pure Compound	1000 ppm	1000 µg 235 µg	0% 76.5%	CA C-PEI

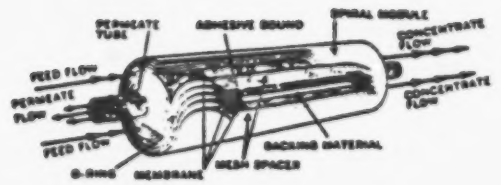
1. Effluent concentration derived from influent concentration and removal efficiency.
2. CA - Cellulose acetate membrane; C-PEI - Cross-linked polyethyleneimine membrane; - AP - Aromatic polyamide membrane; PB - polybenzimidazole membrane.

SOURCE: Touhill, Schukrow and Associates, Inc.; Concentration Technologies for Hazardous Aqueous Waste Treatment; Prepared for Municipal Environmental Research Lab, Feb. 81.



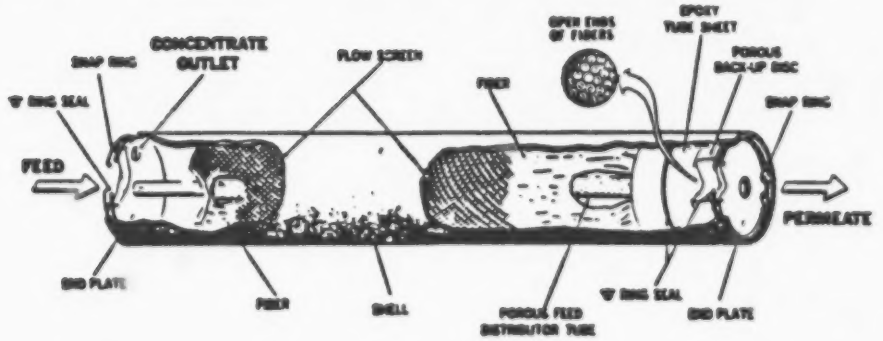
Source: Ref. 1.

FIGURE 1 TUBULAR MODULE



Source: Ref. 1.

FIGURE 2 SPIRAL MEMBRANE MODULE



Source: Ref.17.

FIGURE 3 HOLLOW FIBER MODULE

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FIGURE 2.11 COMMERCIAL MEMBRANE CONFIGURATIONS (BERKOWITZ, ET. AL., 1978)

SECTION 2.12

ION EXCHANGE

Process Description

Ion exchange is a process which reversibly exchanges ions in solution with ions retained on a reactive solid material called ion exchange resin. A typical ion exchange system has a fixed bed of ion exchange resin, where the resin has either the ability to exchange positively charged ions (cation exchange) or negatively charged ions (anion exchange). Depending on the charge of the resin, anions or cations will be held by electrostatic forces to the charged sites. Resins are presaturated with weakly adsorbed monovalent ions, which are readily desorbed and replaced by feed stream ions with greater affinity for the resin. Most commonly, the presaturant ion for cation exchange is either hydrogen or sodium, while anion exchange resins uses either hydroxyl ion or chloride. Generally, divalent and trivalent ions have a higher affinity for ion exchange than monovalent ions. Thus toxic metal cations like divalent cadmium and nickel and anions like divalent chromate and selenate are well-removed by ion exchange.

When the useful exchange capacity of the hydrogen cation exchange resins are exhausted, they are regenerated with a dilute acid solution and a dilute hydroxide solution for the cation and anion resins, respectively.

Sodium-form cation exchangers and chloride-form anion exchangers are regenerated with salt solutions. In all cases, the ions removed from the waste stream end up concentrated in the spent regenerant.

A typical process schematic for a basic two step cation/anion ion exchange system is presented in Figure 2.11a. The ion exchange system presented in this schematic includes series treatment with separate cation and anion exchange systems. These systems contain both anion and cation exchange resin in the same vessel and are capable of producing an effluent water of almost theoretical chemical purity.

The pressure vessels used for ion exchange typically range in size from two to six foot diameter for prepackaged modular systems (i.e. to handle 25 gpm to 300 gpm flowrates) on up to a maximum custom size of twelve feet diameter (i.e. maximum 1150 gpm flowrates). The side height of these vessels vary between six and ten feet in height to provide adequate resin storage, distribution nozzle layout, and freeboard capacity for bed expansion during backwashing. The nominal surface loading of

ion exchange vessels typically range from 8 to 10 gpm per square foot.

Applicability to the Treatment of Hazardous Wastes

Ion exchange is more of a "polishing" technology than a separation technology. It is typically the final technology used to clean a wastewater stream for reuse as process water. In almost all applications it is necessary to pretreat a waste stream prior to the ion exchange system for removal of suspended solids, organics, and oxidizing agents.

The electroplating and metal finishing industry make wide use of ion exchange typically in closed loop systems to reuse rinse water in plating rinse tanks. Wastewaters containing chromium, cadmium, nickel, metal-cyanide complexes, and other dilute metals are presently treated by ion exchange. In some cases, the metals can be recovered for recycle to a plating bath.

Anion exchange is used for the removal and recovery of chromate, a corrosion inhibitor, from cooling tower blowdown streams.

Weak-base anion exchange resins, which adsorb strong acids, are now being applied to the recovery of acids like HNO_3, H_2SO_4, and HF from chemical milling, etching and anodizing solutions used in metal forging and finishing. The highly corrosive spent solutions which contain high concentrations of dissolved metals are pumped through a resin bed. The acid is adsorbed while dissolved metal salts pass through the bed. The resin is regenerated with water, recovering metal-free acid solution for reuse. Eco-Tec Limited commercialized this technology in 1977 and markets a skid-mounted acid purification unit (APU). Data on a specific application of this technology for the recovery of 50 percent (W/W) nitric acid from a nickel-stripping process is presented in Table 2.12a. (Ref. K. Munns, Eco-Tec, Limited).

TABLE 2.12a. DATA FOR APU

Stream	Nitric Acid (g/L)	Nickel (g/L)
Process Solution before APU	990	20
Process Solution with APU	670	5-7
APU Product Stream	620	1-2
APU Waste Stream	50	4-5

Table 2-12b follows which summarizes the review of recent literature in the use of ion exchange as abstracted from selected recent issues of "Amber-Hi-Lites" published periodically by Rohm and Haas Company as compiled by Mr. Charles T. Dickert.

Environmental Considerations

Ion exchange processes generate a concentrated regenerant stream that must be managed. This chemical regenerant stream volume can be as low as two percent of the feed volume if the ion exchange system is operating efficiently. If a facility has a precipitation/ neutralization system on-site, the regenerant stream can be directed to this system.

TABLE 2.12. WHAT'S HAPPENING IN ION EXCHANGE?
A REVIEW OF RECENT LITERATURE
CHARLES T. DICKERT

The Process	The Resin	Of Significance	Where	Ref.
		METALS		
Photoprocessing	Amberlite IRA-400	These resins remove silver from process rinse water and show little drop in capacity after 8 cycles. Ag is eluted with 30% ammonium thiosulfate from which Ag can be recovered and the electrolyte recycled. The resin is then treated with 5% H_2SO_4 before going back on stream. Alternatively, the resin can be regenerated several times with 5% H_2SO_4 without removing Ag, to increase the Ag loading before regenerating with thiosulfate.	Eastman Kodak Rochester, NY	J. Appl. Photogr. Eng 1980, 6(1), 14-18 (93:101036s)
Uranium	Anion	The chemical consumption for acid leach circuits when using NO_3, Cl or H_2SO_4 for elution was evaluated. No dramatic changes in equipment size and resin inventory are anticipated unless new and better ion exchange resins are developed. The elution efficiency of H_2SO_4 circuits could be improved. More concentrated eluates could be produced at lower chemical consumption.	Himsley Eng. Ltd. Toronto, Ont. Can.	CIM Bull. 1980, 73 (814), 107-14 (93: 11308c)
Sodium Chlorate	IRC-84 IRA-400	Chromate was removed from an aqueous solution of sodium chlorate by passing the stream upflow through a column containing these two resins. Chromate was recovered from the resin with a 4% NaOH/8% NaCl solution. The resins were further treated with an 8% NaCl/4% HCl solution before treating more sodium chlorate solution. (The CA abstract does not cover the role of IRC-84 in this process. I assume it is there to remove Cr^{+3} and other metal impurities. The use of HCl with NaCl in the second step of the regeneration could involve removal of these metals from IRC-84 since the NaCl by itself should be adequate to convert OH groups of IRA-400 to the Cl form).	Pennwalt Corp.	Jpn. Kokai Tokkyo Koho 79, 145, 37613 Nov. 1979 (93: 10252t)

TABLE 2.12 (Continued). WHAT'S HAPPENING IN ION EXCHANGE? A REVIEW OF RECENT LITERATURE
CHARLES T. DICKERT

The Process	The Resin	Of Significance	Where	Ref.
Aromatic Purification	Amberlyst 15 Wofatit KS-10	Aromatic hydrocarbons when in contact with H_2SO_4 can form compounds which are colored. Either of these two strong acid resins catalytically converted the impurities into volatile derivatives. The process is improved by using feeds containing 50-200 ppm H_2O. The catalytic activity was retained for at least 10,000 bed volumes.	Inst. Chem. Przem Warsaw, Pol.	Przem. Chem. 1980, 59(11-12), 603-6 (Pol) (94: 174481p)
Gibberellenic Acid	Amberlite XAD-4	A fermentation liquor containing 350 units of gibberellenic acid/liter was passed through a column of the adsorbent. The gibberellenic acid was eluted with 90% acetone in water. The yield was about 80% which is better than is achieved with activated carbon.	Instytut Chemii Przemyslowej	Braz. Pedido Pi 80 00, 883 21 Oct. 1980 (94: 119495w)
Mercaptans to disulfides	Amberlyst A-21	This weak base resin was impregnated with an aqueous solution containing cobalt phthalocyanine monosulfate and NaOH. After drying it can be used as a sweetening catalyst. In an example, a 58 ppm sulfur content in a catalytic cracker distillate was reduced to 1 ppm by contact with the resin catalyst at room temperature for 5 min.	UOP, INc.	Belg,. 882, 106 01 Jul 1980 (94: 124383n)
Acrylamide Purification	Amberlite IR-120 Lewatit MP-62 Amberlite IRA-45	A 33% acrylamide solution obtained by hydrating acrylonitrile with a copper containing catalyst contains up to 300 ppm acrylonitrile and up to 80 ppm Cu as impurities. It is purified by passing the solution through the cation exchanger, the tertiary amine weak base resin (MP-62) and finally the primary/secondary amine weak base resin (IRA-45). After drying, the polyacrylamide is completely soluble in water and has good flocculating properties for suspended solids.	Mitsui Toatsu Chemicals, Inc.	Ger. Offen. 3,019,555 11 Dec. 1980

TABLE 2.12 (Continued). WHAT'S HAPPENING IN ION EXCHANGE?
A REVIEW OF RECENT LITERATURE
CHARLES T. DICKERT

The Process	The Resin	Of Significance	Where	Ref.
Diketene Removal	IRA-68	Water is added to crotonaldehyde containing 3.78% diketene and passed through the weakly basic resin giving an effluent containing no diketene. In contrast, the effluent contained 3.59% diketene when using IRA-400. Water addition is 0.5 mol-equivalent based on the diketene.	Daicel Chemical Industries, Ltd.	Jpn. Kokai Tokkyo Koho 80 22,627 18 Feb. 1980 (93: 4597g)
		MISCELLANEOUS		
Microbicide	Amberlite IRA-400	Iodine was adsorbed on this resin. When this form of the resin containing 42.5% I was used at the 50 ppm level it completely inhibited spore germination of *Alternaria kikuchiana*.	Tokyo Organic Chemical Industries, Ltd., Japan	Jpn. Tokkyo Koho 80, 12, 882 04 Apr. 1980 (93: 232700b).
Humic Acids	Amberlite IRA-904 Lewatit OC-1002	These highly porosity strongly basic resins were evaluated for the removal of humic acid and organic substances from Sava River water. The OH form of Lewatit OC-1002 removed 72.3% and 77.6% of organic substances humic acid, respectively. The Cl form of IRA-904 removed 76.8 and 86.2.	Tehnol. Fak Zagreb, Yugoslavia	Prehrambe-no-Tehnol. Rev. 1979 17(4) 161-4 (Serbo-Croatian) (93: 137812f)

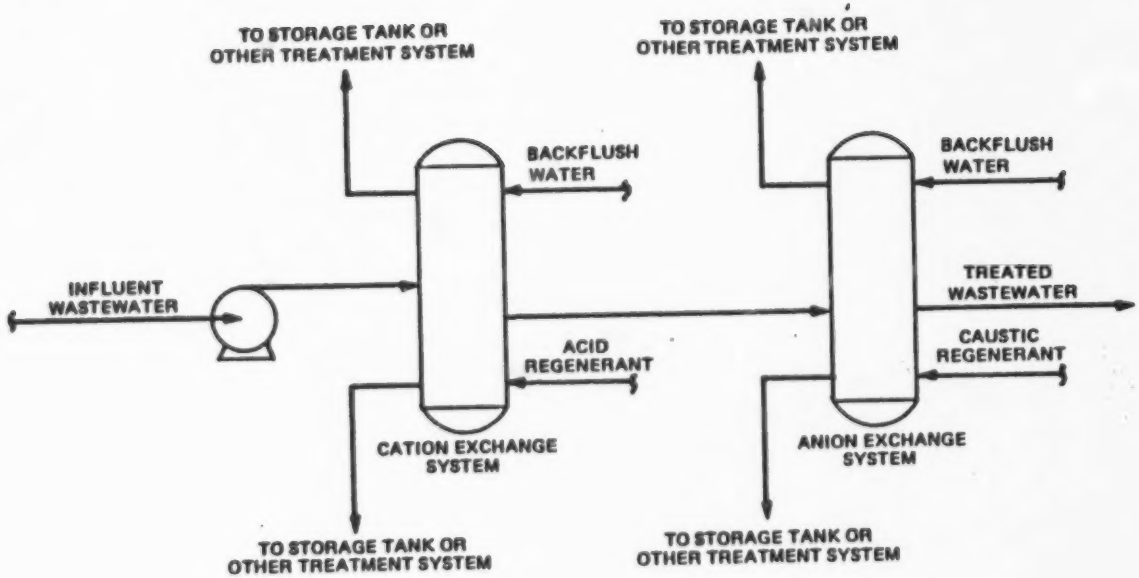


FIGURE 2.12 SCHEMATIC OF ION EXCHANGE

SECTION 2.13

CARBON ADSORPTION

Process Description

Carbon adsorption is a separation technology used to remove and/or recover dissolved organics and certain inorganics from single-phase fluid streams. The material used in carbon adsorption technology is referred to as Granular Activated Carbon (GAC). Activated carbon includes any amorphous form of carbon that has been specially treated (i.e., activated) to increase the surface area/volume ratio of the carbon. The surface of the carbon is generally non-polar with a few polar sites, due to the interaction of the surface with oxygen.

Constituents are adsorbed onto the surface via physical forces, such as van der Waals forces, and chemical forces, referred to as chemisorption. The adsorption forces are comparatively weak and therefore the reverse process, desorption, is also possible. This reversible process allows the carbon surface to be regenerated.

The majority of carbon adsorption systems use cylindrical pressure vessels, which contain the activated carbon. The stream to be treated can flow through the vessel in an upward or downward flow design mode. The velocity of the upward flowing stream can be set so that the carbon bed is expanded and fluidized or so that it is not expanded. The bed expansion configuration in the GAC system upward flow design mode allows the GAC unit to handle influents which contain suspended solids without appreciable pressure drop. The GAC system downward flow design mode develops high pressure drop with suspended solids accumulation and typically requires upstream filtration as a pretreatment step. In addition, the stream can flow through the beds in series or in parallel. The upward flowing bed expansion process can be supplemented by periodically pulsing new carbon into the bed. This periodic pulsing of carbon, which replaces the same amount of spent carbon that is rejected, allows the carbon adsorption process to continue without scheduled downtime.

A diagram for a carbon adsorption system is presented at the end of this section. This diagram illustrates a parallel configured carbon adsorption system.

Applicability to the Treatment of Hazardous Wastes

Carbon adsorption processes have been used extensively to treat industrial wastewaters containing dissolved organic materials and certain inorganic constituents. Contaminants that are typically removed from aqueous streams include BOD, TOC,

phenol, color, cresol, polyethers, various halogenated organics, cyanide, and chromium.

At a commercial hazardous waste treatment facility which processes 40,000 gallons of mixed metal and organic-contaminated aqueous waste per day, carbon adsorption is the final polishing step in a process train that includes oxidation, precipitation, filtration, and neutralization. The carbon system consists of two downflow beds in series. Although TOC breaks through within two or three days, phenol concentration is the controlling parameter due to a stringent discharge permit limit. Phenol breakthrough occurs in about 28 days. Spent carbon is returned to the supplier for off-site regeneration.

Full-scale activated carbon systems are installed at numerous facilities around the world. The design flow rate at these facilities ranges from 5,000 gallons per day at an explosive facility in Switzerland to 20,000,000 gallons per day at one of American Cyanamid's facility in Bound Brook, New Jersey. The activated carbon treatment system at American Cyanamid's facility consists of ten 16 foot diameter carbon columns which operate in an upflow expanded bed configuration.

Table 2.13a presents the results of applying GAC technology to aqueous wastes containing toxic organics. Table 2.13b presents the amenability of various organic compounds to carbon adsorption.

Carbon adsorption is not generally used in the treatment of non-aqueous process streams. This is because the less polar the solvent stream, the less likely it will be that constituents are removed from a relatively non-polar solvent to a non-polar carbon surface.

Environmental Considerations

The activated carbon used in the carbon adsorption process eventually reaches a point where it will no longer adsorb material. This spent activated carbon must then be either regenerated or discarded. The most common form of regeneration is thermal regeneration, although various types of chemical regeneration are used. Chemicals used for regeneration include acids, bases, and solvents.

The amount of material removed in carbon adsorption systems will be dependent on the characteristics of the process stream and its constituents. Most carbon treatment efficiencies are greater than 99 percent with influent concentrations below 1,000 ppm. At higher concentrations, removal efficiencies can reach 99.9%.

TABLE 2-13A. TOXIC COMPOUNDS REMOVED FROM WATER USING THE CARBON ADSORPTION SYSTEM IN THE HAZARDOUS MATERIAL SPILLS TREATMENT TRAILER

Compound	Location of incident	Quantity treated (gallons)	Contact time (minutes)	Influent Concentration (ppb)	Effluent Concentration (ppb)	Percent removal
DNBP	Clarksburgh, New Jersey	2,000,000	26	8	< .002	99.98
PCB	Seattle, Washington	600,000	30-40	400	< .075	99.98+
Toxaphene	The Plains, Virginia	250,000	26	36	1	97.22
Chlordane	Strongstown, Pennsylvania	100,000	17	13	.35	97.3
		3,000	240	1,430	.43	99.99
Heptachlor	Strongstown, Pennsylvania	100,000	17	6.1	.06	99.02
		3,000	240	80	.1	99.87
Aldrin	Strongstown, Pennsylvania	100,000	17	8.5	.19	97.76
		3,000	240	60.5	.15	99.75
Dieldrin	Strongstown, Pennsylvania	100,000	17	11	< .01	99.99+
		3,000	240	60.5	< .01	99.99+
Kepone	Hopewell, Virginia	225,000	45.5	4,000	< 1	99.98
Pentachlorophenol	Haverford, Pennsylvania	215,000	26	10,000	< 1	99.98
Methylene Chloride	Oswego, New York	250,000	8.5	190	51	73.15
Carbon Tetrachloride	Oswego, New York	250,000	8.5	1.1	< .1	90.91+
Benzene	Oswego, New York	250,000	8.5	1	.1	90
Toluene	Oswego, New York	250,000	8.5	120	.3	99.75
Xylene	Oswego, New York	250,000	8.5	140	< .1	99.92+
Trichloroethane	Oswego, New York	250,000	8.5	12	< .1	99.17+
Trichloroethylene	Oswego, New York	250,000	8.5	21	.3	98.57

Source: Becker, D.L., S.C. Wilson, 1978

TABLE 2.13B. AMENABILITY OF TYPICAL ORGANIC COMPOUNDS TO ACTIVATED CARBON ADSORPTION

Compound	Molecular Weight	Aqueous Solubility (%)	Concentration mg/l Initial (C_o)	Concentration mg/l Final (C_e)	Adsorbability g compound/ g carbon	Adsorbability Percent Reduction
Alcohols						
Methanol	32.0	∞	1,000	964	0.007	3.6
Ethanol	46.1	∞	1,000	901	0.020	10.0
Propanol	60.1	∞	1,000	811	0.038	18.9
Butanol	74.1	7.7	1,000	466	0.107	53.4
n-Amyl alcohol	88.2	1.7	1,000	282	0.155	71.8
n-Hexanol	102.2	0.58	1,000	45	0.191	95.5
Isopropanol	60.1	∞	1,000	874	0.025	12.6
Allyl alcohol	58.1	∞	1,010	789	0.024	21.9
Isobutanol	74.1	8.5	1,000	581	0.084	41.9
t-Butanol	74.1	∞	1,000	705	0.059	29.5
2-Ethyl butanol	102.2	0.43	1,000	145	0.170	85.5
2-Ethyl hexanol	130.2	0.07	700	10	0.138	98.5
Aldehydes						
Formaldehyde	30.0	∞	1,000	908	0.018	9.2
Acetaldehyde	44.1	∞	1,000	881	0.022	11.9
Propionaldehyde	58.1	22	1,000	723	0.057	27.7
Butyraldehyde	72.1	7.1	1,000	472	0.106	52.8
Acrolein	56.1	20.6	1,000	694	0.061	30.6
Crotonaldehyde	70.1	15.5	1,000	544	0.092	45.6
Benzaldehyde	106.1	0.33	1,000	60	0.188	94.0
Paraldehyde	132.2	10.5	1,000	261	0.148	73.9
Amines						
Di-N-Propylamine	101.2	∞	1,000	198	0.174	80.2
Butylamine	73.1	∞	1,000	480	0.103	52.0
Di-N-Butylamine	129.3	∞	1,000	130	0.174	87.0
Allylamine	57.1	∞	1,000	686	0.063	31.4
Ethylenediamine	60.1	∞	1,000	893	0.021	10.7
Diethylenetriamine	103.2	∞	1,000	706	0.062	29.4
Monethanolamine	61.1	∞	1,012	939	0.015	7.2
Diethanolamine	105.1	95.4	996	722	0.057	27.5
Triethanolamine	149.1	∞	1,000	670	0.067	33.0
Monoisopropanolamine	75.1	∞	1,000	800	0.040	20.0
Diisopropanolamine	133.2	87	1,000	543	0.091	45.7
Pyridines & Morpholines						
Pyridine	79.1	∞	1,000	527	0.095	47.3
2-Methyl-5-Ethyl pyridine	121.2	sl.sol.	1,000	107	0.179	89.3
N-Methyl morpholine	101.2	∞	1,000	575	0.085	42.5
N-Ethyl morpholine	115.2	∞	1,000	467	0.107	53.3
Aromatics						
Benzene	78.1	0.07	416	21	0.080	95.0
Toluene	92.1	0.047	317	66	0.050	79.2
Ethyl benzene	106.2	0.02	115	18	0.019	84.3
Phenol	94	6.7	1,000	194	0.161	80.6
Hydroquinone	110.1	6.0	1,000	167	0.167	83.3
Aniline	93.1	3.4	1,000	251	0.150	74.9
Styrene	104.2	0.03	180	18	0.028	88.8
Nitrobenzene	123.1	0.19	1,023	44	0.196	95.6
Esters						
Methyl acetate	74.1	31.9	1,030	760	0.054	26.2
Ethyl acetate	88.1	8.7	1,000	495	0.100	50.5
Propylacetate	102.1	2	1,000	248	0.149	75.2
Butyl acetate	116.2	0.68	1,000	154	0.169	84.6
Primary amyl acetate	130.2	0.2	985	119	0.175	88.0

TABLE 2.13B (Continued). AMENABILITY OF TYPICAL ORGANIC COMPOUNDS TO ACTIVATED CARBON ADSORPTION

Compound	Molecular Weight	Aqueous Solubility (%)	Concentration mg/l Initial (C_o)	Concentration mg/l Final (C_e)	Adsorbability g compound/ g carbon	Adsorbability Percent Reduction
Esters						
Isopropyl acetate	102.1	2.9	1,000	319	0.137	68.1
Isobutyl acetate	116.2	0.63	1,000	180	0.164	82.0
Vinyl acetate	86.1	2.8	1,000	357	0.129	64.3
Ethylene glycol monoethyl ether acetate	132.2	22.9	1,000	342	0.132	65.8
Ethyl acrylate	100.1	2.0	1,015	226	0.157	77.7
Butyl acrylate	128.2	0.2	1,000	43	0.193	95.9
Ethers						
Isopropyl ether	102.2	1.2	1,023	203	0.162	80.0
Butyl ether	130.2	0.03	197	nil	0.039	100.0
Dichloroisopropylene ether	171.1	0.17	1,008	nil	0.200	100.0
Glycols & Glycol Ethers						
Ethylene glycol	62.1	∞	1,000	932	0.0136	6.8
Diethylene glycol	106.1	∞	1,000	738	0.053	26.2
Triethylene glycol	150.2	∞	1,000	477	0.105	52.3
Tetraethylene glycol	194.2	∞	1,000	419	0.116	58.1
Propylene glycol	76.1	∞	1,000	884	0.024	11.6
Dipropylene glycol	134.2	∞	1,000	835	0.033	16.5
Hexylene glycol	118.2	∞	1,000	386	0.122	61.4
Ethylene glycol monomethyl ether	76.1	∞	1,024	886	0.028	13.5
Ethylene glycol monoethyl ether	90.1	∞	1,022	705	0.063	31.0
Ethylene glycol monobutyl ether	118.2	∞	1,000	441	0.112	55.9
Ethylene glycol monohexyl ether	146.2	0.99	975	126	0.170	87.1
Diethylene glycol monoethyl ether	134.2	∞	1,010	570	0.087	43.6
Diethylene glycol monobutyl ether	162.2	∞	1,000	173	0.166	82.7
Ethoxytriglycol	178.2	∞	1,000	303	0.139	69.7
Halogenated						
Ethylene dichloride	99.0	0.81	1,000	189	0.163	81.1
Propylene dichloride	113..0	0.30	1,000	71	0.183	92.9
Ketones						
Acetone	58.1	∞	1,000	782	0.043	21.8
Methylethyl ketone	72.1	26.8	1,000	532	0.094	46.8
Methyl propyl ketone	86.1	4.3	1,000	305	0.139	69.5
Methyl butyl ketone	100.2	v. sl. sol.	988	191	0.159	80.7
Methyl isobutyl ketone	100.2	1.9	1,000	152	0.169	84.8
Methyl isoamyl ketone	114.2	0.54	986	146	0.169	85.2
Diisobutyl ketone	142.2	0.05	300	nil	0.060	100.0
Cyclohexanone	98.2	2.5	1,000	332	0.134	66.8
Acetophenone	120.1	0.55	1,000	28	0.194	97.2
Isophorone	138.2	1.2	1,000	34	0.193	96.6
Organic Acids						
Formic acid	46.0	∞	1,000	765	0.047	23.5
Acetic acid	60.1	∞	1,000	760	0.048	24.0
Propionic acid	74.1	∞	1,000	674	0.065	32.6
Butyric acid	88.1	∞	1,000	405	0.119	59.5
Valeric acid	102.1	2.4	1,000	203	0.159	79.7
Caproic acid	116.2	1.1	1,000	30	0.194	97.0
Acrylic acid	72.1	∞	1,000	355	0.129	64.5
Benzoic acid	122.1	0.29	1,000	89	0.183	91.1
Oxides						
Propylene oxide	58.1	40.5	1,000	739	0.052	26.1
Styrene oxide	120.2	0.3	1,000	47	0.190	95.3

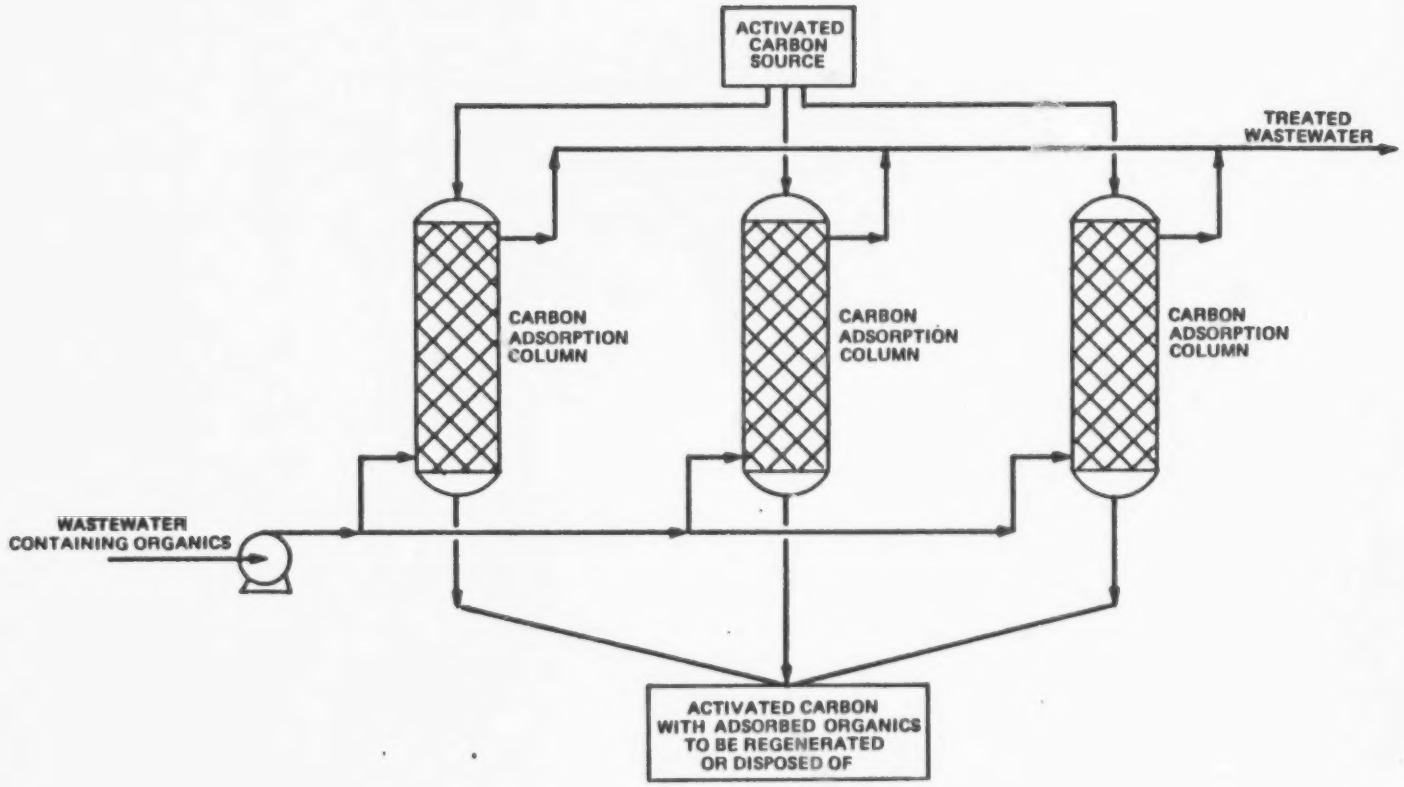

ACTIVATED CARBON SOURCE
TREATED WASTEWATER
CARBON ADSORPTION COLUMN
CARBON ADSORPTION COLUMN
CARBON ADSORPTION COLUMN
WASTEWATER CONTAINING ORGANICS
ACTIVATED CARBON WITH ADSORBED ORGANICS TO BE REGENERATED OR DISPOSED OF

FIGURE 2.13 SCHEMATIC OF CARBON ADSORPTION

SECTION 2.14

RESIN ADSORPTION

Process Description

Resin adsorption is a process by which an organic substance is removed from an aqueous waste and can be recovered, if desirable. The process involves adsorption of organics onto a synthetic resin in a fixed bed. Usually the waste is fed in a downflow mode to the resin bed, which is contained in an enclosed cylindrical stainless steel or rubber-lined steel tank. Resin adsorbents are used in much the same way as granular carbon. However, in resin adsorption, the strength of the attractive forces between the solute molecules and the resin is usually weaker than that associated with adsorption on carbon. This allows for easier regeneration of the resin and improved potential for recovery of the adsorbed substances.

The adsorptive capabilities depend to a great degree on the specific type of resin used. The chemical nature of resins may vary significantly from one resin to another. Different types of resins have affinities for different types of chemical compounds.

Because the influent to the adsorption tanks must be low in suspended solids (in some cases less than 10 ppm), filtration units often precede the adsorption units.

In many cases, adsorption will be pH dependent, and thus, pH adjustment will be necessary prior to treatment. Strong oxidants, which would chemically attack the resins, must be removed from the influent stream. This process would typically be used as a polishing step. A resin adsorption system is shown in Figure 2.14.

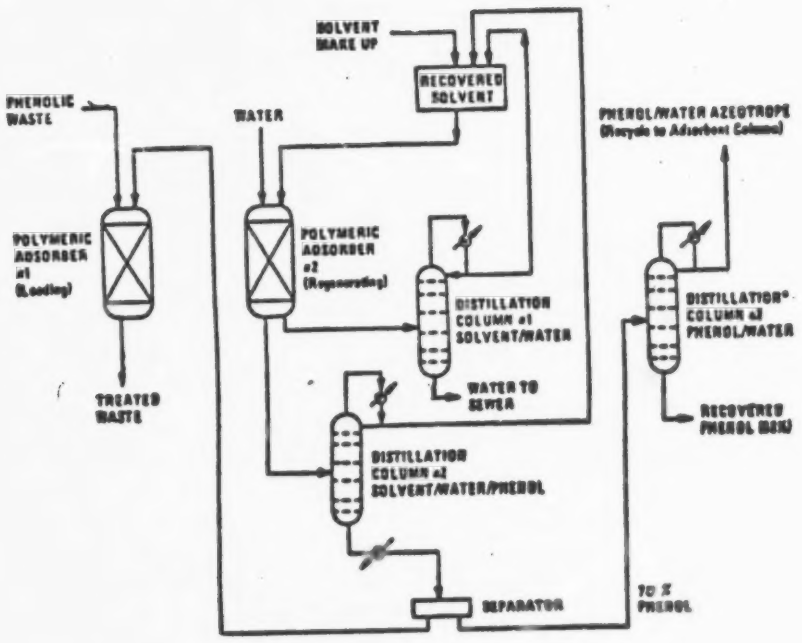
Applicability to the Treatment of Hazardous Waste

Resin adsorption is commonly used for removal of phenol from waste streams. Full-scale installations include an Indiana plant, which uses resin adsorption to recover phenol from its waste stream and a plant in West Virginia, which uses a resin adsorption system to remove phenol and high molecular weight polycyclic hydrocarbons from a waste stream. Reportedly, a resin adsorption system was installed at the Naval Ammunition Depot in McAlister, Oklahoma, to remove such contaminants as TNT, 2,4-DNT, RDX (cyclotrimethylenetrinitramine), and HMX (cyclotetramethylenetetranitramine) from aqueous wastes (DeRenzo, 1978). Resin adsorption for removal of explosive materials is more economical than carbon adsorption since the carbon cannot be thermally regenerated once its capacity has been used up.

Regardless of the source of the waste, it is necessary that the feed stream to the resin adsorption system be a single liquid phase.

Environmental Considerations

Spent resin regenerants, if not reused, must be disposed of. Frequently, disposal has been either by incineration or land disposal.



Column #3 utilized when highly pure phenol is required.

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SOURCE: DeRENZO, 1978)

FIGURE 2.14 SCHEMATIC OF RESIN ADSORPTION SYSTEM FOR REMOVAL AND RECOVERY OF PHENOL

SECTION 2.15

STEAM STRIPPING

Process Description

Steam stripping is the removal of gases or volatile organics from a dilute wastewater. This process is identical to steam distillation (see section 2.9, DISTILLATION) except that the wastewater is fed at the top of the column. Reintroduction of a portion of the recovered material into the column (reflux or recycle) increases the removal efficiency (De Renzo, 1978). A schematic of a steam stripper is presented in Figure 2.15.

Applicability to the Treatment of Hazardous Waste

Steam stripping is a widely used to strip hydrogen sulfide gas (H_2S) and ammonia (NH_3) from refinery "sour" waste and ammonia from coke oven gas. It also removes phenol in the first process, and has been tested for use in removal of immiscible volatile chlorinated organics. For the potentially banned hazardous wastes it is applicable to phenol and immiscible, volatile organics, whether chlorinated or unchlorinated (Kiang and Metry, 1982.)

Removal efficiencies of 99.7 percent or better of ammonia and hydrogen sulfide gases are possible from feed solutions containing 0.3% NH_3 and 0.7% H_2S by weight. Phenol-containing solutions retain from 150-750 ppm after stripping and may require further treatment. (Kiang and metry 1982). Removal efficiencies approaching 90% have been observed for feed streams containing 3,000-6,000 ppm of chlorinated hydrocarbons using a column 3 feet in diameter with 20 feet of packing (GSRI, 1979).

At one solvent recycling facility, steam stripping is used to recover residual solvent from aqueous still bottoms.

Steam stripping is suitable for liquids only which contain volatile chemicals. It is not as well developed for use on immiscible organic removal as it is for ammonia and sulfide gas removal. Table 2.15a presents some toxic organic compounds which can be easily steam stripped and Table 2.15b presents some performance data for steam stripping of organics.

Environmental Considerations

The stripped liquid may require further treatment (e.g. carbon adsorption) if the chemical of concern has not been removed to desired levels. Since the contaminants are present in small concentrations in the aqueous waste, still bottom residues rarely develop.

TABLE 2-15A. SOME TOXIC ORGANIC COMPOUNDS WHICH CAN EASILY BE STEAM STRIPPED

Benzene	Vinyl chloride
Chlorobenzene	1,2-Dichloropropane
Dichlorobenzenes	1,3-Dichloropropene
Ethylbenzene	Hexachlorobutadiene
Toluene	Hexachlorocyclopentadiene
Styrene	Methyl bromide
Xylenes	Dichlorofluoromethane
Methyl chloride	Dichloroethylenes
Methylene chloride	Trichloroethylene
Chloroform	Tetrachloroethylene
Carbon Tetrachloride	Allyl chloride
Chloroethane	Toxaphene
1,1-Dichloroethane	Isoprene
1,1,1-Trichloroethane	Carbon disulfide
Hexachloroethane	Cyclohexane

Source: Analysis of Operation and Emissions from Typical Hazardous Waste Treatment Processes. Prep. by Water General Corp. for the Commonwealth of Massachusetts, Dept. of Environmental Management, Bureau of Solid Waste Disposal, Dec. 1982.

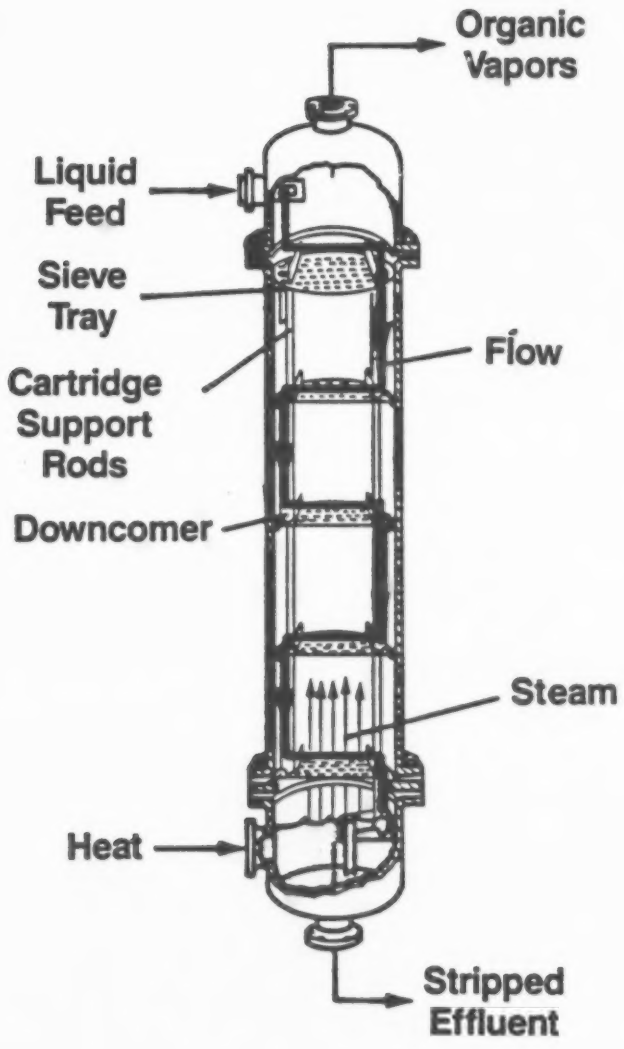
TABLE 2-15B. STEAM STRIPPING PERFORMANCE

Compound	Influent (mg/l)	Effluent (mg/l)	Percent removal
Stripper 1			
Dichloromethane	1,430	< 0.0153	> 99.99
Carbon tetrachloride	< 665	< 0.0549	> 99.99
Chloroform	< 8.81	1.15	< 86.9
Stripper 2			
Dichloromethane	4.73	< 0.0021	> 99.95
Chloroform	< 18.6	< 1.9	89.8
1,2-Dichloroethane	< 36.2	4.36	< 88.0
Carbon tetrachloride	< 9.7	< 0.030	99.7
Stripper 3			
Methylene chloride	34	< 0.01	> 99.97
Chloroform	4,509	< 0.01	> 99.99
1,2-Dichloroethane	9.030	< 0.01	> 99.99

Source: Jett, G.M., Development Document for Expanded Best Practicable Control Technology, Best Conventional Control Technology, Best Available Control Technology in the Pesticides Chemicals Industry, Effluents Guidelines Division, U.S. EPA, EPA-440/1-82-0796, November 1982.

The stripped material is concentrated in the condensed steam overhead product. In some cases, the material may be recovered for reuse. Where recovery is not practical, this concentrated waste stream requires further treatment, incineration, or disposal.

FIGURE 2.15
STEAM STRIPPING COLUMN—
PERFORATED TRAY TYPE



Source: Pfaudler, Rochester, New York

SECTION 2.16

AIR STRIPPING

Process Description

Air stripping is a process that uses forced air to remove undesired constituents from a liquid phase. This process is ideal for aqueous hazardous waste streams containing organics that are volatile and only slightly soluble in water. Other factors important in the removal of organics from wastewater in air stripping are temperature, pressure, air to water ratio, and the surface area available for mass transfer.

There are several types of air stripping processes. These include sprays and spray towers, mechanical aeration, diffused aeration, and packed towers.

Packed towers can achieve up to 99.9 percent removal of some volatile compounds from aqueous wastes while the other aeration devices have removal efficiencies in the range of between 50 and 90 percent. The system selected will depend on the physical/chemical characteristics of the waste stream.

A packed tower air stripper schematic is presented at the end of this section. Tower diameters on these units range from one foot to 14 feet with packing heights as high as fifty feet. Depending on the volatility of the contaminants, air to water volumetric ratios may range from 10 to 1 up to 300 to 1.

Applicability to the Treatment of Hazardous Wastes

Air stripping is an appropriate technology for the removal of slightly water soluble, volatile organics from aqueous hazardous wastes and contaminated groundwater. This technology has only been recently used in the full-scale treatment of hazardous waste streams, but numerous pilot studies are being performed to determine other applications.

Packed tower air stripping has been utilized to clean up groundwater aquifers contaminated with chlorinated hydrocarbons. These compounds generally have water solubilities of less than 10,000 mg/l and are very amenable to removal using air stripping. Contaminant concentrations have been on the order of 0.1 mg/l to 5 mg/l. Data from air stripping of contaminated groundwater are presented in Table 2-16.

Air stripping is an appropriate technology for a well characterized waste stream containing volatile organics. If the waste stream contains other constituents, pretreatment and post-treatment technologies may be needed. Suspended solids and

dissolved metals that will be oxidized to an insoluble form must be removed before the stream enters the packed tower or fouling will occur. It is often necessary to pilot test waste streams to assure that air stripping is an appropriate technology. This technology is most applicable to waste streams with concentrations below 100 mg/l.

Environmental Considerations

Air stripping produces air emissions of the stripped volatile compounds. Containment of these emissions is difficult when using mechanical aeration or sprays, but, the off-gas from a packed tower can be directed through a carbon adsorption unit to clean the off-gas.

TABLE 2.16. AIR STRIPPING TREATMENT RESULTS

Results from Remedial Action of Groundwater Contamined by Landfill Leachate

Parameter	Range of Concentrations, ug/l Untreated	Treated
Chloroform	<1. - 38.	<1. - 5.
Methylene chloride	8. - 45.	<1. - 3.
1,1-Dichloroethylene	<0.2 - 2.0	<0.2 - <0.2
Tetrachloroethylene	<1. - 9.	<1. - 2.
Cis-1,2-dichloroethylene	8. - 35.	<1. - 1.
Trans-1,2-dichloroethylene	<1. - 13.	<1. - 2.
Trichloroethylene	21. - 108.	<1. - 9.
1,1-Dichloroethane	4. - 22.	<1. - 2.
1,2-Dichloroethane	<1. - 2.	<1. - <1.
1,1,1-Trichloroethane	2. - 13.	<1. - 2.
1,1,2-Trichloroethane	<1. - <1.	<1. - <1.
1,2-Dichloropropane	<1. - 3.	<1. - <1.

ref: Wenck, 1984.

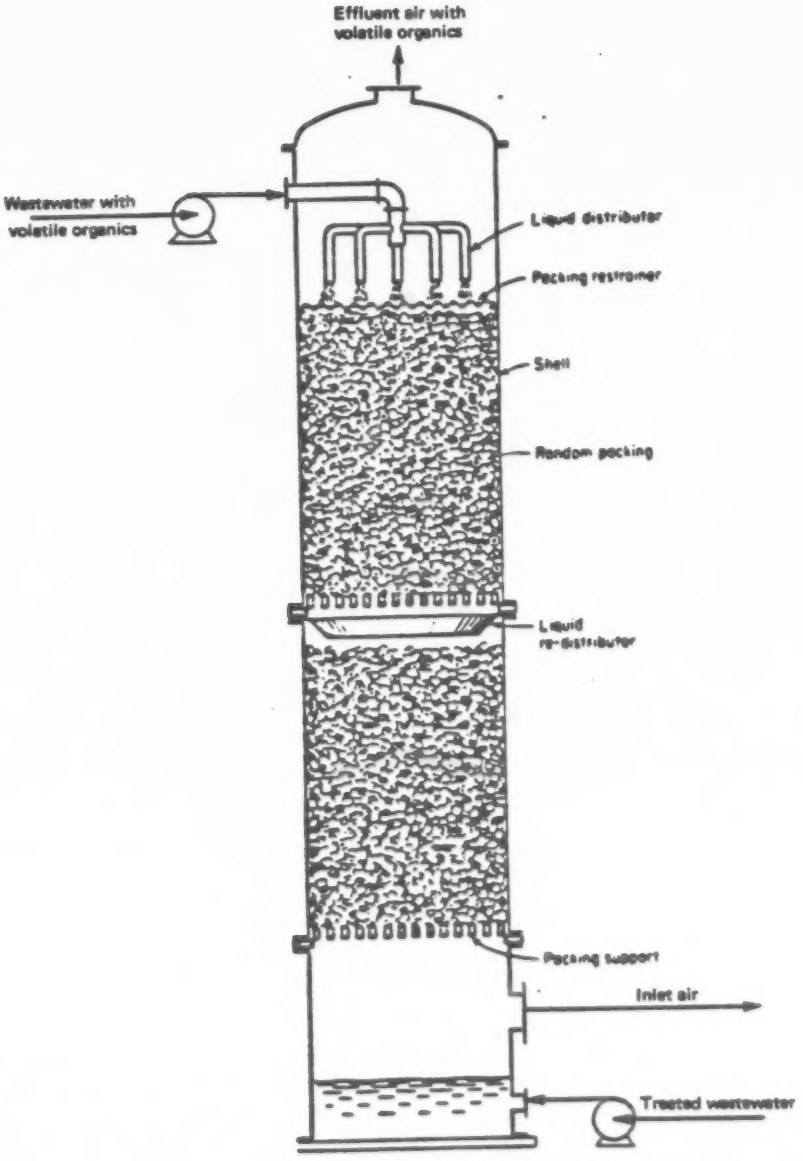


FIGURE 2.16 SCHEMATIC OF AIR STRIPPING

SECTION 2.17

SOLVENT EXTRACTION

Process Description

Solvent extraction is a process whereby a dissolved or adsorbed substance is transferred from a liquid or solid phase to a solvent that preferentially dissolves that substance. When the waste to be treated is a liquid (often water) the process may be called liquid-liquid extraction, the substance transferred is the solute, the treated effluent is referred to as the raffinate and the solute-rich solvent phase is called the extract. For the process to be effective, the extracting solvent must be immiscible in the liquid and differ in density so that gravity separation is possible and there is minimal contamination of the raffinate with solvent.

Solvent extraction can be performed as a batch process or by the contact of the solvent with the feed in staged or continuous contact equipment. The solvent and the wastewater are agitated in one vessel (the mixer) and then transferred to another vessel (the settler) where the phases are separated by density differences. This operation can occur more than once so that there are multiple mixer-settler stages. Another option, which is depicted in Figure 2.17, is continuous countercurrent contact in a vertical column such as a spray tower, packed tower, or sieve plate tower.

Applicability to the Treatment of Hazardous Wastes

Solvent extraction is used to remove organic contaminants from aqueous wastes in several industries including petroleum refining, organic chemicals manufacturing, pulp and paper, and iron and steel.

There has been a full-scale solvent extraction operation for 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) tested at the Syntex Agribusiness facility in Verona, Missouri. The 2,3,7,8-TCDD was extracted from distillation bottoms at this facility with six to eight successive hexane washes resulting in a reduction from 340 to 0.1 to 0.5 ppm 2,3,7,8-TCDD concentrations.

Aqueous and organic solvents have been tested in the laboratory for extracting 2,3,7,8-TCDD from various soil types. The results of these tests have been positive. Chemical Waste Management Company has reported success with solvent extraction of 2,3,7,8-TCDD from soil. They experienced removal efficiencies of 99 percent. They are continuing to perform bench tests on solvent extraction.

Solvent extraction is a limited technology in that it is almost always necessary to further treat the raffinate and/or the extract. This technology is typically used when it is not economical or possible to use more standard technologies. The removal efficiency of solvent extraction depends on the solvent, the constituent to be extracted, soil properties, if a constituent is being extracted from soil, the liquid containing the constituent, and the unit operation design. Typical removal efficiencies vary from 80 percent to close to 100 percent. Table 2.17 presents extraction removal efficiencies for a halogenated hydrocarbon waste from a petrochemical manufacturer.

It is often possible to reuse the solvent in the solvent extraction process. This is accomplished by using a distillation column to remove the extracted solute molecules from the solvent in a concentrated form and then reusing the distilled solvent.

In addition, the cost of solvent extraction is relatively high. The high cost of solvent extraction results from initial solvent costs, further treatment of the extract, such as distillation, and disposal costs of the extracted constituents.

Environmental Considerations

Liquid-liquid extraction results in two streams, the raffinate and the extract, which usually require further treatment. If aqueous, the raffinate may be contaminated with small quantities of both the solute and the solvent. These may have to be removed by carbon adsorption or biological degradation. Solvent is typically recovered from the extract by distillation, leaving a concentrated solute-solvent waste stream for incineration or disposal.

Solvent extraction from soil or sludges produces an extract and a solvent-saturated solid phase. The solid may be rendered nonhazardous by evaporation of the solvent.

TABLE 2.17. EXTRACTION OF AQUEOUS HALOGENATED HYDROCARBON WASTES FROM PETROCHEMICAL MANUFACTURING WITH C_{10}- C_{12} SOLVENT AND KEROSENE

(Solvent to Waste Ratio 7 to 1)

Organic Compound	Influent (mg/l)	Kerosene Effluent (mg/l)	C_{10}-C_{12} Hydrocarbon Effluent (mg/l)
Vinyl Chloride	1	1	1
Ethyl Chloride	3	1	1+
Vinylidene Chloride	13	1	1
Dichloroethylene	49	2	1+
Chloroform	--	--	--
Ethylene Dichloride	320	--	16
Carbon tetrachloride	--	--	--
Trichloroethylene	24	6	5
Trichloroethane	75	2	3
Perchloroethylene	14	2	1
Tetrachloroethane	148	7	6
Pentachloroethane		2	--
Unknown		2	1
Total		43	36
Percent Removed		94	95
Solubility of Solvent in water in mg/l	--	30	20

Ref: U.S. EPA, April, 1979.

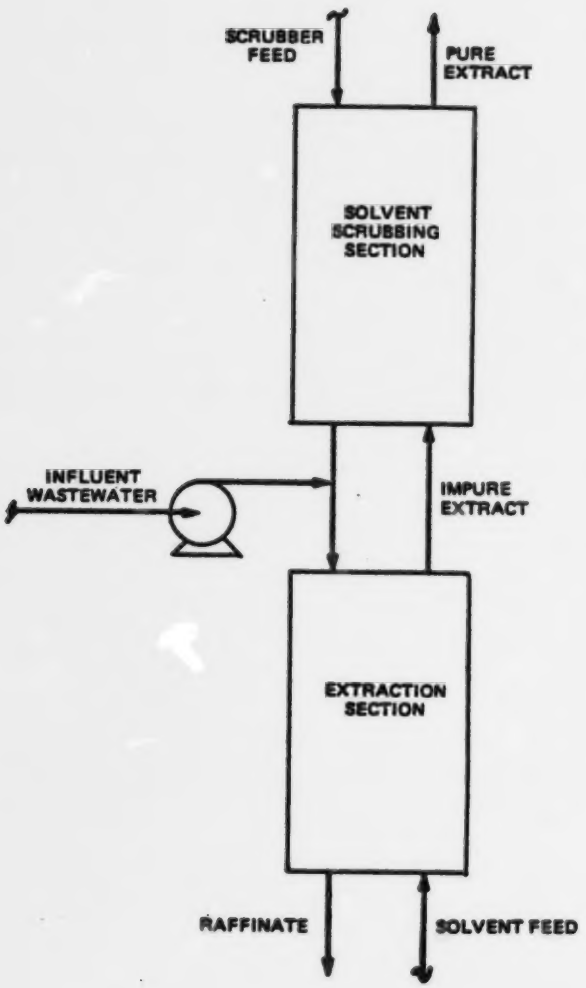


FIGURE 2.17 SCHEMATIC OF SOLVENT EXTRACTION